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STUDIES RELATING TO MARKET PROJECTIONS FOR ADVANCED WASTE TREATMENT

Louis Koenig

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

July 1964

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STUDIES RELATING TO MARKET PROJECTIONS

FOR

ADVANCED WASTE TREATMENT

A Report For

The Advanced Waste Treatment Research Program

U. S. Public Health Service
Robert A. Taft Sanitary Engineering Center
4676 Columbia Parkway
Cincinnati 26, Ohio

NATIONAL TECHNICAL
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U.S. Department of Commerce
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By

Louis Koenig - Research
San Antonio, Texas

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CHAPTER 1

/S/ Edward J. [illegible]

INTRODUCTION

Under the Advanced Waste Treatment Research Program, the U. S. Public Health Service is engaged in the study of processes which might be used to treat various waste waters in order to make them indefinitely reuseable. The impetus toward such studies arises from two distinct but related approaches. One of these, the "clean streams" impetus looks toward improving the quality of water in the Nation's streams so that they may be beneficially used for a number of purposes. The other, the "more water" impetus, looks toward increasing the quantity of water available for municipal and industrial uses.

Advanced waste treatment involves some radical departures in our methods of handling municipal and industrial water borne wastes. While there is qualitative agreement on the desirability of such processes for application in particular instances where needed, there have been no quantitative data applicable to what, in commercial practice, would be called the economic and market research aspects. Such studies, in industrial practice, would include a determination of the costs of the processes or equipment, the total size of the market, the time schedule under which the market will develop, the geographical distribution of the market, the impact of competitive processes, and the capabilities or equipment sizes in which the process will be used. In commercial practice, this information is of importance not only to the sales department but also to the research and development department since many aspects of the direction of the research and development derive directly from such factors.

The present AWTR Program was initiated by and is under the sponsorship and guidance of a government agency rather than a commercial concern. Nonetheless, the above principles of sound planning and economics equally apply. Recognizing this, the AWTR Program initiated discussion with Louis Koenig-Research on July 12, 1962 concerning such economic research. A proposal entitled "Market Projections for Advanced Waste Treatment" was submitted in May 1963 and, after several revisions, Contract No. PH 86-64-39 was executed October 22, 1963. The Project Officer was Dr. David G. Stephan, Deputy Chief of the Program.

The work covered by the contract comprised three phases of the original proposal which are presented in Chapters 3, 4, and 5 of this report. These three phases, constituting only a part of a complete economic study, were those of greatest interest to the Program at the time of contracting and those which could be performed within the limited funds available.

The work was begun November 1, 1963 and was completed except for report finalizing on July 24, 1964.

LK-R staff members contributing to the work were: Louis Koenig, Project Director; Larry Jureski, Beatrice Aldrich and Ray Shofner, Research Assistants; and Louis Arias, John Loughlin, Ralph Hight, Dennis Drake, Guadalupe Lopez, Dennis McMahon, David Barra and Nelson Finch, Research Aides.

CHAPTER 2

SUMMARY

This investigation explores three aspects of the economics of advanced waste treatment. It identifies the streams in the nation for which the major portion of the municipal waste discharges thereto have received the highest possible degree of conventional treatment, i.e., those for which advanced waste treatment would be the next step in further pollution control. It surveys, by means of a sample of 155 cities, the extent to which the surface water sources of municipalities contain water which has previously passed through an upstream municipal waste collection and/or waste treatment system. It explores advanced waste treatment itself and certain ultimate disposal measures for possible logistical imbalances with regard to the use of materials and resources.

Streams With Complete Treatment

For each stream and stream reach in the nation greater than approximately 100 miles in length, there was cumulated downstream the total discharge volume reaching the stream from upstream municipal waste systems and the cumulative fraction of BOD removed as weighted by the volume of discharge. This cumulative fraction serves as an index of the degree of treatment of the upstream waste water discharges. Streams having cumulative fractions of 0.9 or over are those for which all municipal discharges are already receiving the highest possible degree of conventional treatment; they are, thus, those for which the next step in control of municipal waste discharges would be advanced waste treatment. The lower the index, the less the probability that advanced waste treatment would be called upon as the next step in stream improvement.

More than 4% of the 100-mile basins in the nation are now in the 0.9-and-over class and these constitute about 2% of the national land area. The volume of municipal effluent involved comprises 15% of the total recoverable municipal discharge reaching the nation's streams, excluding the small coastal basins. The actual volume involved is about 1.5 bgd (over 1.5 million acre-ft per year) of which about 1.3 bgd is contributed by the city of Chicago. The geographic distribution of the "0.9 index" basins is highly concentrated in the Western Gulf and Mississippi River Basins in which the percentages of waste flows amenable to advanced waste treatment comprise about 23% and 28% respectively of the total recoverable municipal discharges. The only such basin east of the Mississippi is theDesPlaines River to which Chicago contributes.

For the greater-than-0.85 index category, i.e., those basins now approaching complete conventional treatment, the percent of the total number of 100-mile basins is about 11, the percent of the nation's area about 10, and the total discharge about 2.2 bgd corresponding to about 22% of the nation's recoverable municipal discharge. For the two largest basins sytems included, the percents of discharge volumes covered are about 48 for the Western Gulf Basins and 35 for the Mississippi Basin. Seven distinct basins east of the Mississippi are included.

In any given basin having a large recoverable municipal discharge, the major portion of the total comes from relatively few cities.

It is concluded, under the philosophy of the present study, that to attain a higher degree of pollution control for the great majority of the nation's streams at the present time, recourse would be made to providing additional conventional treatment rather than to the application of advanced waste treatment. However, for a small, but not insignificant percentage of the nation's streams, the municipal waste discharges thereto even today receive as high a degree of treatment as can be reached with conventional means. For these streams, the next step in achieving a higher degree of pollution source control would be advanced waste treatment. The reader is cautioned that this study covers only one of the factors that enter into the determination of the market for advanced waste treatment and that certain other of these factors may be of more importance in determining the market than the one under study.

Waste in Surface Supplies

A study was made of the percentages of upstream municipal waste water present in the surface water supplies of a sample of 155 U. S. Cities of population 25,000 or over. The study was an attempt to clarify the extent, nationwide, to which surface water supplies are composed of previously used water.

The data for the sample, representing 38% of all cities having surface water supplies and 34% of the U. S. population served by surface supplies, show that the range of upstream municipal waste water present in the low-flow past the water supply intake is from 0% to over 20%, with a median based on population served of 3.5%. The low-flow is taken as that for the minimum flow month in the 1961 water year. In simpler terms, this analysis indicated that for the population experiencing median re-use, each 30 gallons of water flowing past their intake during the low-flow month contained one gallon of water which had passed through the sewerage system of an upstream community. For the population experiencing the upper 10% of water re-use, the corresponding figure is 8%, signifying that 1 gallon in 12 had passed through an upstream sewerage system.

The present study did not consider upstream industrial discharges. If the national average ratio of industrial to municipal water withdrawals (approximately 14:1) should be considered as applying to the municipal industrial waste volumes at each municipal intake, the median reuse factor (upstream waste discharges/low-flow) would be of the order of 0.5 and for the worst cases in the sample, of the order of 3. Such reuse factors may be compared with the occasionally cited but poorly supported statements that the reuse factor (based on withdrawals rather than returns) for the Ohio river is 6, and for the Verdigris River in Kansas is 17, based

on low-flow. They also may be compared with a recent documented study giving the withdrawal reuse factor of the Ohio at Cincinnati as 2.71 based on low-flow. The present study shows that such figures applicable to individual sites may be not at all unreasonable. A great deal depends upon the definition used for low-flow, however, since the value varies greatly with various definitions.

Speaking to the psychological hurdle in direct reuse, if the current reuse factors developed in this study should be considered appreciable in the minds of the public, such information could become a psychological advantage for advanced waste treatment rather than a psychological obstacle. For if the reuse factor is considered excessive, there are but two choices: either to be drinking used water which has been deliberately processed by advanced techniques to remove all contaminants, or to be drinking used water from which it is known that conventional processes cannot remove all contaminants and which, in the face of this knowledge, has been placed in the river upstream with only the hope that nature will take care of it.

Logistical Imbalances

In the exploration for possible logistical imbalances in the technology of advanced waste treatment, there was constructed the distribution of municipal waste flows by flow rate for the approximately 11,000 sewered communities in the nation. It was found that 50% of the nation's waste water production occurs in systems of less than 38 mgd, 30% in systems of greater than 100 mgd, and 30% in systems of less than about 4 mgd. The average sewage flow per community is about 1.25 mgd. An economic model of AWT plants, assuming that AWT was applied to every sewered community, was constructed from this distribution. When the model was used, however, it was found that the total consumptions of national resources were so small that the variations in unit consumption by size of plant were insignificant and need not have been taken into account.

Application of AWT in the form of distillation-adsorption systems would require a fuel consumption of less than 6% of the nation's total fuel production and an electrical energy consumption of less than 1/2% of the total power generation. The sulfuric acid used would be about 3.5% of U. S. production. However, the activated carbon use would be in the neighborhood of 360 tons per day which is about twice the present production.

For advanced waste treatment by adsorption - electrodialysis systems, another likely possibility, the fuel use would be neglibible, the electrical energy about 4% of total national electric energy generation and the sulfuric acid consumption less than 3% of U. S. production. The activated carbon required, however, would amount to 560 tons per day or over three times the present production. The production of electrodialysis membranes of course would be increased - several thousand fold.

In summary, for advanced waste treatment by either of two likely methods, there would be no logistical imbalance for fuel, electric energy, or sulfuric acid; activated carbon production, on the other hand, would have to expand to two or three times its present production rate. There does not seem to be any reason why this could not be readily accomplished.

Exploration was also made for logistical imbalances in various methods of ultimate disposal of advanced waste treatment wastes. For ultimate disposal by incineration, the impact on the economy in fuel, electrical energy, or railroad or tank truck hauling would be quite inconsequential.

For ultimate disposal by pipelining to the ocean, the amount of energy required would be insignificant compared to the national generation and the ton-miles of pipelining would be about 6% of the current ton-miles for oil and products pipelining. These figures are insensitive to assumptions concerning the number of trunk pipelines. A figure for pipeline mileage is directly dependent upon the number of lines assumed and the distances. Assuming 100 trunk lines with an average haul of 700 miles, the AWT pipeline mileage would amount to about 17% of the present cross-country pipeline installations. However, very preliminary studies from another project suggest that optimum disposal by any method will comprise a pooling of the waste to be disposed, that the pattern of such group disposal by conveyance to the ocean will comprise a band around the coast line on the order of 100 miles deep, and that the conveyance in this band as well as the collection systems for other types of group disposal inland will be by truck or rail and not by pipeline. If that is the case, there will be no role for pipelining in ultimate disposal.

In ultimate disposal by injection, if every sewered community had one injection well (a highly unlikely situation in view of the group economy alluded to above), the number of such wells would be only 2% of the existing oil and gas wells. These could be completed within a single year with the existing well drilling capacity of the nation. However, injection wells will probably be deeper than the average oil and gas well. If the average depth were 10,000 feet, the total footage would represent about one-half of the annual footage in the oil and gas industry. However, probably not more than one-half of the nation is suitable for injection well disposal so that the above figures must be correspondingly reduced.

Per Capita Waste Flows

Some studies made in connection with the processing of the basic data provide information not heretofore available. There was determined the average per capita municipal waste flow in three population categories, less than 10,000, 10,000 to 100,000, and greater than 100,000 for each state. The national averages, as gallons per capita day, were 131, 120, 155, resp. and for the over-all average the figure was 141.

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There is some regionalization of these per capita sewage flows. The highest are in the northwest arc from Colorado to California; the lowest are in the southwestern arc from Arizona to Illinois. The simple state averages in these two arcs are 250 and 89 gallons per capita day resp. These figures and the regionalization are based on only the most numerous class, that for populations less than 10,000, and may be different for the total of all population categories.

Statistical analysis shows that there is an upward trend for per capita flows with city population.

Based on the application of the national average gpcd to population served in each population class, the national municipal waste water flow was estimated at 13.8 bgd in 1957.

Average Removals

A special study was made of the very few cases of sewage treatment plant installations in which rapid sand filters or intermittent sand filters are used in place of secondary treatment. The average fraction of BOD removed for six rapid sand filter entries was 0.51 and for 21 intermittent sand filter entries was 0.77.

CHAPTER 3

STREAMS APPROACHING "COMPLETE" TREATMENT

Introduction

Meaning of the f index number

Nature of the "streams"

Results

- By number of entries
- By area
- By geography
- By volume of discharge
- By major contributing cities

Conclusions

* * * * * * * * * * * * *

STREAMS APPROACHING "COMPLETE" TREATMENT

INTRODUCTION

In the early stages of the Advanced Waste Treatment Research Program it was thought likely that advanced waste treatment would be applied, in its pollution control role, to secondary treatment plant effluent. The present work was planned under the influence of that concept, although it was understood at the time and now becomes more evident, that for some AWT processes at least, it may be possible to operate more advantageously on primary effluent.

Even so, judged from the present practice of pollution control, it is unlikely that advanced waste treatment would be suggested for a stream receiving large quantities of raw sewage or primary effluent. It is much more likely that pollution control authorities impelled to clean up such a stream would first recommend the installation of primary treatment on the untreated discharges and secondary treatment on the primary discharges. This at least would be the conventional approach lacking a clearly established practice and economy of advanced waste

treatment. Since the nation as a whole is far from a goal of 100% "complete" treatment, i.e., primary plus secondary treatment, in the present stage of development, pursuit toward that goal by conventional treatment is a major activity of pollution control authorities.

Thus, one must assume as a practical matter (until advanced waste treatment is well developed and demonstrated) that real attempts to market advanced waste treatment processes would be met with a general rebuff approximately in the words, "Why should we go to an expensive and new type operation in search of 100% removal with conventional treatment?". However, if there are streams for which a large percentage of the existing discharges are already receiving "complete" conventional treatment, then on these streams pollution control authorities might well suggest advanced waste treatment as a further pollution control measure.

It is known that in 1957 only 41% of the sewered U. S. communities had secondary treatment plants (1). These data and their regional or state breakdowns do not show the extent to which secondary treatment plants may be grouped together on particular streams. The purpose of the study described in the present Chapter was to determine if there are any streams in the nation for which a large part of the municipal effluent discharging thereto has received secondary treatment. Also of interest, of course, was the actual number of such streams and their geographical locations. If there are such streams, they would constitute prospective areas of application for advanced waste treatment.

The approach was to compute for each stream an index number measuring the fraction of BOD removed by the existing installations. This index number was taken as the average fraction of BOD removed by each community weighted by the volume of each discharge actually reaching the stream.

MEANING OF THE f INDEX NUMBER

The f index number was chosen as a compromise among a number of possible quantities that might measure the approach to "complete" treatment on a stream. From the standpoint of a direct measure of markets, one might use an index representing the percentage of plants having a fraction BOD removed above some critical value. That value, conventionally, would be 0.9 since this represents roughly the expected fraction removed by secondary treatment plants operated in an exemplary manner. However, such a number would not measure the actual influence of the applied treatment on the water quality in the stream. For example, one might find that 8 out of 10 plants on a stream had secondary treatment, but the remaining two plants, employing only primary treatment, might represent a very large proportion of the total waste discharge. Thus, to suggest advanced waste treatment for this stream would be impractical.

The chosen f index number is an attempt to weight the individual fractions removed by the size of the plant. This index number does not quite measure the fraction of the total BOD removed by the existing plants. In part, this comes about because portions of some discharges (effluent used for irrigation) do not reach the stream and, therefore, are not reflected in the cumulative index number. But even if there were none such, the index number still does not quite measure the overall fraction of BOD removed. In order to be a precise measure of this quantity, the individual fractions would have to be weighted, not by the volume, but by the pounds of BOD.

However, a sample study of this discrepancy showed that while theoretically not precise, the cumulative f index is indeed a rather close approximation to the true fraction of BOD removed. The sample study comprised two tabulations, for Texas and Oregon, of all discharges for which both volume flow and pounds of BOD (in terms of population equivalent) were available. It happened that there were twenty eligible entries in each state. The difference between the f index number and the true average fraction removed was +0.8% and -4.5% for Texas and Oregon respectively. This indicates that the f index number measures quite well the overall fraction of BOD removed. Actually, this fact is incidental to the main use of the f index in the present study in which it is simply an indicator of the approach to "complete" treatment on a stream. Streams with high f index numbers are those for which most of the municipal effluent reaching the stream is already highly treated. Streams with low f index numbers are those for which only a small portion of the discharges are highly treated.

The detailed procedures by which the f indices were developed are described in Chapter 6. In the ideal conventional situations in which all secondary plants have individual f's of 0.9, all primary plants have f's of 0.35, and for those without treatment, f = 0.0, a cumulative f of 0.9 would indicate that all discharges along the stream receive secondary treatment. In actual practice, such a sharp cut-off cannot be applied because some plants have known f values which differ from the assumed nominal value. Furthermore, a cumulative f of less than 0.9, say 0.8, might come about through degrading of the 0.9 plants with a moderate percentage of 0.35 plants, or with a small percentage of 0.0 plants. Thus, although it has a precise mathematical derivation, a cumulative f value below 0.9 does not have a single, easily definable meaning. Subject to the restrictions implicit in the above concept, however, the cumulative f does have this real meaning, that the closer it is to 0.9, the more likely is the stream a prospect for advanced waste treatment.

NATURE OF THE "STREAMS"

The nature of the entity termed a "stream" is also described in detail in Chapter 6. It would have been possible, of course, to compute cumulative discharge and cumulative f for every mile of stream in the nation. However, to reduce the study to manageable proportions, only streams having lengths of more than about

100 miles were assessed. At each confluence point of such hundred-mile streams with a main stream, cumulations were made for the tributary and for the main stream above and below the confluence. In addition, if there occurred on a main stream a reach of length greater than 200 miles in which no accumulation points occurred through confluences, then an additional accumulation point was arbitrarily placed so as to have no reach greater than 200 miles without a cumulation point. At each cumulation point the figures refer to all the upstream discharges.

The results of the cumulations are shown in Table 1 and mapped on Figures 1, 2, and 3. The Table is divided into three sections comprising f ranges of 0.900 and up, 0.850 - 0.899, and 0.800 - 0.849.

In each section of Table 1 the entries are divided into two parts. The first part in each section comprises those watersheds for which the accumulation point is also incorporated in some accumulation point in the following parts of the Table. To illustrate, an accumulation point which appears in the first part of the 0.9-and-over section may also contribute to an accumulation point appearing in the second part of the 0.90 section, or in either the 0.85 or the 0.80 sections. In the second part of each section are those accumulation points which do not form part of any basin listed elsewhere in the Table.

By Number of Entries

Table 2 summarizes the data on number of entries in Table 1. About 3% of the eligible accumulation points have cumulative f's of 0.90 or over. This percentage is not a direct measure of the "number of streams approaching complete treatment" because of the complex role of the confluence points. If at a confluence point, the main stream and also the tributary have f's above 0.9, then the f at the accumulation point below the confluence must also be 0.9 or over. But in that case, there would be counted three accumulation points in the 0.9 category while actually only two basins are involved. If either the main stream or the tributary has an f above 0.9 while the other f is below, the accumulation point below the confluence may be 0.9 or it may not be. If it is not, the number of accumulation points above 0.9 would correspond to the number of basins. But if it is, there would have been counted two accumulation points representing essentially only one basin. A better measure of the number of basins approaching complete treatment is obtained by eliminating the "below the confluence" accumulation point both from the tally and from the total. When this is done, as in the last two columns of Table 2, the percent of "basins" in the 0.9-and-over class becomes 4.0%.

While the above is a correct measure for the percentage of basins, it is too low for the percentage of "streams", i.e. 100-mile stream segments. The reason is that each accumulation point on a main stream refers to discharges not only from the 100-mile segment immediately above it but also from all other upstream segments

TABLE 1
STREAMS APPROACHING "COMPLETE" TREATMENT

Entry No.	Name of Accumulation Point	State	Lat.-Long. °N °W	f' Fraction Removed(1)	Upstream Recoverable Municipal Discharge, mgd
1	San Pedro R. acw Gila R.	Ariz.	33 -110 8	.930	.3744
2	Purgatone acw Arkansas	Colo.	38 -103.2	.947	5.0650
3	Big Sioux R. near Sioux Falls	S.D.	44 -98.8	.919	4.7230
4	Pit R. near Lookout	Calif.	41 -121	.900	.9240
5	Feather R. acw Sacramento R.	"	39 -122	.919	5.5058
6	Mokelumne acw San Joaquin	"	38 -121.6	.900	4.4525
7	Nueces R. near Crystal City	Tex.	28.6 -100	.902	.3760
8	San Antonio R. acw Guadalupe	"	28.4 -97	.966	72.7970
9	Guadalupe R. at New Braunfels	"	29.8 -98	.937	.8000
10	Leon R. at Gatesville	"	31.5 -98	.903	.8720
11	Little R. acw Brazos R.	"	31 -97	.906	11.3180
12	Mustang Cr. acw Canadian R.(2)	"	38.8 -102.4	.900	.1200
13	Des Plaines R. acw Illinois	Ill.	41.4 -88.3	.902	1305.6710
14	Des Moines R. acw E. Des Moines R.	Iowa	43 -94	.978	3.6215
15	Raccoon R. acw Des Moines	"	41.6 -93.6	.976	5.1142
16	Iowa R. acw Cedar R.	"	41.3 -91.3	.917	23.9823
17	Platte R. near Saratoga	Wyo.	41.6 -107	.962	.4170
18	Laramie R. acw N. Platte R.	"	42.1 -104.5	.902	1.8500
19	Grand R. acw Missouri R.	S.D.	45.8 -100.6	.927	.2200
20	Big Sioux R. acw Missouri	S.D.	42.5 -96.5	.906	18.4930
21	Arikaree Cr. acw Republican R.	Neb.	40.0 -101.5	.900	.8520
22	Eel R. at Pacific Ocean	Calif.	40.6 -124.0	.902	1.9210
23	Salinas R. at Pacific Ocean	"	36.7 -122.0	.909	7.0840
24	San Antonio R. at Gulf of Mex.	Tex.	28.4 -97	.909	85.5689
25	Santa Rosa acw Gila R.	Ariz.	33.2 -112.2	.862	5.9936
26	Arkansas R. acw Cucharas R.	Okla.	38.2 -104.2	.865	32.0685
27	N. Canadian acw Canadian R.	Colo.	35.3 -95.5	.885	46.7549
28	Powder R. near Broadus	Mont.	45.2 -105.6	.887	.7641
29	San Joaquin acw Modelumne	Calif.	38.0 -121.6	.878	51.0680
30	Salt R. acw Brazos R.	Tex.	33.2 -100.0	.857	1.3590
31	White R. at Plainview	"	34.0 -101.5	.896	1.1650
32	Running Water Cr. near Clovis	"	35.5 -102.6	.890	.0760
33	Colorado R. at LaGrange	"	30.0 -97.0	.872	33.1210
34	Brazos R. acw Navasota R.	"	30.3 -96.0	.871	32.5508
35	Brazos R. bcw Navasota R.	"	30.3 -96.0	.865	35.8608
36	Brazos R. acw Little R.	"	31.0 -97.0	.854	21.0150
37	Brazos R. bcw Little R.	"	31.0 -97.0	.869	32.3330
38	Canadian R. bcw Mustang R.(2)	"	35.5 -102.4	.873	.2030
39	N. Canadian R. at Texhoma (3)	Okla.	36.6 -102.0	.885	.2480
40	N. Canadian R. at Hooker (3)	"	36.8 -101.0	.875	.7140

41	Big Sandy West R. acw Elm R.	Tex.	33.0 -97.0	.862	41.0360
42	Elm R. acw Big Sandy West R.	"	33.0 -97.0	.858	5.3860
43	Trinity R. bcw Big Sandy & Elm R.	"	33.0 -97.0	.862	46.4220
44	Sabine R. near Longview	"	32.4 -94.5	.878	7.3270
45	Neches R. acw Angelina R.	"	31.0 -94.0	.858	2.3670
46	Illinois R. acw Mississippi	Ill.	39.0 -90.5	.891	1453.6545
47	Illinois R. near Beardstown	"	40.0 -90.4	.892	1445.2745
48	Illinois R. near Peoria	"	41.0 -89.5	.896	1374.4335
49	Illinois R. bcw Des Plaines	"	41.4 -88.3	.898	1326.5423
50	Cedar R. at Waterloo	Iowa	42.4 -92.0	.858	37.2414
51	Des Moines R. bcw Raccoon R.	"	41.6 -93.6	.872	18.1691
52	Iowa R. bcw Cedar R.	"	41.3 -91.3	.875	63.5953
53	Iowa R. acw Mississippi	"	41.0 -91.0	.872	63.8123
54	Concho R. acw Colorado	Tex.	31.5 -99.2	.885	.1400
55	Humboldt R.	Nev.	40.6 -117.0	.875	1.2600
56	Little Colorado R. acw Colorado	Ariz.	36.0 -111.8	.870	1.6226
57	Powder R. acw Yellowstone R.	Mont.	46.7 -105.4	.854	.7941
58	San Juan R. acw Colorado R.	Utah	37.0 -111.0	.866	8.5405
59	Osage R. acw Missouri R.	Mo.	38.5 -92.0	.851	31.9041
60	Gasconade R. acw Missouri R.	"	38.5 -92.0	.865	.8440
61	Hatchie R. acw Mississippi	Miss.	38.6 -90.0	.875	4.5270
62	Calcasieu R. at Gulf of Mex.	La.	30.0 -93.3	.858	11.7310
63	Chickasaw R. acw Pascagcoula	Miss.	31.0 -88.8	.853	9.9225
64	San Joaquin R. acw Sacramento	Calif.	38.0 -122.0	.880	55.5205
65	Colorado R. at Gulf of Mex.	Tex.	28.6 -96.0	.865	35.8900
66	Brazos R. at Gulf of Mex.	Tex	29.0 -95.2	.861	42.1218
67	Red Lake R. acw Red R. (into Canada)	Minn.	48.0 -97.0	.877	2.6280
68	Neches R. at the Gulf of Mex.	Tex.	30.0 -94.0	.852	26.9530
69	Little Wabash acw Wabash R.	Ill.	38.0 -88.0	.871	3.9720
70	Scioto R. acw Ohio	Ohio	38.8 -83.0	.885	102.2458
71	St. Joseph R. at Lake Michigan	Mich.	42.0 -86.0	.851	73.8915
72	Kaskaskia R. acw Mississippi	Ill.	38.0 -90.0	.874	14.7820
73	Gila R. acw Santa Rosa	Ariz.	33.2 -112.2	.829	6.9315
74	Gila R. bcw Verde R.	"	33.2 -112.3	.830	6.9315
75	Arkansas R. bcw Cucharas R.	Colo.	38.2 -104.2	.822	34.0725
76	Arkansas R. acw Purgatone R.	"	38.0 -103.2	.812	38.4813
77	Arkansas R. bcw Purgatone R.	"	38.0 -103.2	.825	43.5463
78	Arkansas R. acw Sandy Cr.	"	38.2 -102.5	.833	46.2863
79	Arkansas R. bcw Sandy Cr.	"	38.2 -102.5	.831	47.3726
80	Arkansas R. near Larned	Kans.	38.0 -99.0	.828	51.1950
81	Arkansas R. near Wichita	"	38.0 -98.0	.830	60.9999
82	Chikaskia R. acw Salt R.	Okla.	36.6 -97.2	.809	3.5255
83	Salt R. acw Chikaskia R.	"	36.6 -97.2	.817	1.5341
84	Salt R. bcw Chikaskia R.	"	36.6 -97.2	.813	5.0596
85	Arkansas R. acw Salt R.	"	36.6 -97.2	.815	105.9307
86	Arkansas R. bcw Salt R.	"	36.6 -97.2	.815	110.9903

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87	Arkansas R. acw Cimarron R.	Okla.	36.0 -96.4	.814	111.7107
88	Deep Fork R. acw Canadian R.	"	35.3 -95.5	.814	4.4708
89	Osage R. near Osceola	Mo.	38.0 -94.0	.804	12.2771
90	White R. acw E.F. White R.	Ind.	38.5 -87.2	.817	146.9549
91	White R. bcw E.F. White R.	"	38.5 -87.2	.809	174.2729
92	Tuolumne acw San Joaquin	Calif.	37.6 -121.2	.814	13.4700
93	Pecos R. near Carlsbad Caverns	N.M.	32.0 -104.0	.845	9.9500
94	Pecos R. at Pecos	Tex.	31.4 -103.3	.847	9.9500
95	Pecos R. at Rankin	"	31.0 -102.0	.849	9.9500
96	Pecos R. acw Rio Grande R.	"	29.8 -101.3	.849	9.9500
97	Rio Grande acw Pecos R.	"	29.8 -101.3	.813	48.2088
98	Rio Grande bcw Pecos R.(acw Devil R.)	"	29.8 -101.3	.820	58.1588
99	Rio Grande bcw Devil R.	"	29.8 -101.0	.819	58.1588
100	Rio Grande near Bennett	"	30.6 -105.0	.812	48.2088
101	Rio Grande near Redford	"	29.5 -104.2	.813	48.2088
102	Rio Grande bcw Maravillas Cr.	"	29.6 -102.8	.813	48.2088
103	Rio Grande near Eagle Pass	"	29.0 -101.0	.821	59.3258
104	Rio Grande acw Rio Puerco R.	"	34.3 -107.0	.813	27.8788
105	Rio Grande at El Paso	"	32.0 -106.0	.812	48.1488
106	Arkansas R. near Lakin	Kans.	38.0 -101.0	.830	47.9135
107	Elm Fork Red R. acw Red R.	Okla.	99.0 -34.4	.818	3.5880
108	Dogtown & Tule Crs. at Memphis	Tex.	34.6 -101.0	.839	.9970
109	Wichita R. acw Red R.	Tex-Okla.	34.0 -98.0	.848	1.1810
110	Washita R. near Clinton	Okla.	35.5 -99.0	.833	1.3590
111	Washita R. near Lindsay	"	34.9 -97.7	.810	3.9588
112	Washita R. acw Red R.	"	34.0 -97.0	.810	5.6498
113	Red River acw Little R.	Kans.	33.6 -93.9	.805	56.6391
114	Trinity R. near Fairfield	Tex.	32.0 -96.0	.849	147.5790
115	Trinity R. near Huntsville	"	31.0 -95.5	.848	149.2740
116	Sabine R. near Hemphill	"	31.2 -93.8	.824	9.8825
117	Angelina R. acw Neches R.	"	31.0 -94.0	.829	6.8730
118	Neches R. bcw Angelina R.	"	31.0 -94.0	.836	9.2400
119	KasKasKia R. near Vandalia	Ill.	39.0 -89.0	.828	3.0050
120	Des Moines R. bcw E. Des Moines R.	Iowa	43.0 -94.0	.824	4.3210
121	Des Moines acw Raccoon R.	Iowa	41.6 -93.6	.832	13.0549
122	Skunk R. acw North Skunk	"	41.0 -92.0	.836	6.4990
123	Skunk R. bcw North Skunk	"	41.0 -92.0	.828	7.0459
124	Des Moines R. acw Mississippi	"	40.4 -91.4	.804	40.0458
125	Salt R. acw Mississippi	Mo.	39.4 -91	.831	3.2760
126	Cedar River acw Iowa R.	Iowa	41.3 -91.3	.849	39.6130
127	Colorado River acw Llano(3)	Tex.	30.7 -98.5	.811	6.4040
128	Colorado River bcw Llano(3)	"	30.7 -98.5	.802	6.9070
129	Brazos acw Clear Fork Brazos(2)	"	33 -98.7	.848	2.4280
130	Clear Fork Brazos acw Brazos(3)	"	33 -98.7	.801	2.0220
131	Brazos R. bcw Clear Fork Brazos (2)	"	33 -98.7	.831	4.4500

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132	Brazos River near Blum (3)	Texas	32.1 -97.5	.842	6.4030
133	Colorado R. acw San Saba(3)	"	31.2 -98.7	.812	6.2640
134	Colorado R. bcw San Saba (3)	"	31.2 -98.7	.810	6.4040
135	Double Mountain Fork acw Salt Fork Brazos (2)	"	33.3 -100	.836	.5370
136	Beals Cr. acw Sulphur Springs Creek (2)	"	32.1 -101.7	.819	.7070
137	Beals Cr. bcw Sulphur Springs Creek (2)	"	32.1 -101.7	.830	.7070
138	Concho River acw Colorado (2)	"	31.5 -99.2	.885	.1400
139	Colorado River acw with Concho(3)	"	31.5 -99.2	.805	4.2560
140	Colorado River bcw Concho (3)	"	31.5 -99.2	.815	4.3960
141	Gila River bcw Salt R.	Ariz.	33.4 -112.3	.801	12.2805
142	Maumee River at Lake Erie	Mich.	42 -83	.815	115.3880
143	Gila River near Montezuma	Ariz.	33 -113	.809	13.5411
144	Arkansas R. bcw Cimarron R.	Okla.	36 -96.4	.812	22.5091
145	Caney R. acw Verdigris R.	"	36.3 -95.6	.839	2.1788
146	Neosha R. acw Arkansas R.	"	35.9 -95.2	.806	29.2188
147	Canadian R. bcw Deerfork & North Cr.	"	35.3 -95.5	.813	75.3877
148	Wind River near Thermopolis	Wy.	43.5 -108.2	.830	2.2369
149	Marias R. acw Missouri R.	Mont.	48 -110.5	.823	1.3550
150	Little Sioux R. acw Missouri	Iowa	42 -96	.812	6.2259
151	Lodgepole Cr. acw S. Platte R.	Colo.	41 -102.5	.849	2.5810
152	Frenchmans Cr. acw Republican R.	Neb.	40.2 -101	.847	1.4011
153	Nodaway R. acw Missouri R.	Mo.	40 -95	.831	1.5467
154	Grand R. acw Missouri R.	"	39.4 -93.2	.817	4.3530
155	White R. acw Wabash R.	Ind.	38.4 -87.8	.808	174.6829
156	Black Water & Yellow R. at Gulf	Fla.	30.5 -87	.842	1.6620
157	Satilla R. at Atlantic Ocean	Ga.	31 -81.5	.829	5.5358
158	Saluda R. acw Broad R.	S.C.	34 -81	.816	17.0920
159	Blackwater & Bannister R. acw Roanoke R.	Va.	36.6 -78.8	.832	18.7433
160	Cape Fear R. at Lillington	N.C.	35.4 -78.8	.832	44.4687
161	Delaware River at Portland	Pa.	41 -75	.807	14.0903
162	Nueches R. acw Frio R.	Texas	28.5 -98.2	.818	.6240
163	Rio Grande at Laredo	"	27.7 -99.8	.821	59.3288
164	Red R. acw Sulphur R (bcw Little R.)	Kans.	33.1 -93.9	.801	58.2755
165	Trinity R. at Gulf of Mexico	Texas	30 -95	.847	151.8530
166	Sabine R. at Gulf of Mexico	"	30 -94	.818	12.6185
167	Mississippi bcw Illinois	Ill.	39 -90.5	.801	2021.1210

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NOTES FOR TABLE 1:

(1) $f' = \frac{\Sigma Qf + .9\Sigma[Q]}{\Sigma Q + \Sigma[Q]}$ = f including irrigation type discharges

Q = mgd reaching stream other than by irrigation
f = fraction BOD removed
[Q] = mgd reaching stream through irrigation

(2) For these accumulation points the fraction, P, of the flow resulting from irrigation type contributions is in the range of .5 - .84. Where P was >.84, accumulation point was omitted from the Table. $P = \frac{\Sigma[Q]}{\Sigma Q + \Sigma[Q]}$

(3) For these accumulation points P is in the range .2 - .5. For points without Note (2) or (3), P is negligible.

(4) acw = above confluence with
bcw = below confluence with

TABLE 2

SUMMARY OF ACCUMULATION POINTS BY f CATEGORY

f' (1)	No. of accumulation points	% of eligible points	No. of acc. pts. less BCW's	% of basins
.80 and over	167	21.1		
.85 and over	72	9.0	65	10.8
.90 and over	24	3.1	24	4.0
Single eligibles (2)	219			
Triple eligibles (2)	191			
Total eligibles	792	100	601	

(1) - f' is the fraction removed including the irrigation type discharges.

(2) - Eligibles are accumulated points other than map boundary points, etc.
Single eligibles are accumulation points having a single accumulation.
Triple eligibles are the accumulation points at confluences having three accumulations.

To determine the number of such upstream segments above each accumulation point for which $f \geq 0.9$, would involve a considerable amount of work, not justified, it was thought, by the results to be gained. It was felt that a better picture of the totality of eligible streams is obtained from the maps and from the basin land areas as presented in Table 3.

TABLE 3

TOTAL LAND AREAS OF BASINS BY CATEGORY

f	% of National Area
.90 and over	2.2
.85 and over	9.8
.80 and over	ca 30

The basins in the 0.90 and over category comprise 2.2% of the conterminous U. S. area of about 3 million square miles.

By Geography

The three maps, Figures 1, 2, and 3, show the locations of the stream basins with cumulative f's of 0.90-and-over, 0.85-and-over, and 0.80-and-over resp. The numbers on the indicated basins correspond with the Entry Numbers in Table 1.

Not all of the 24 accumulation points for f = 0.9-and-over in Table 1 are shown on the map as some of them are incorporated in larger basins in the same f category. For example, Entry No. 24, the San Antonio River below its confluence with the Guadalupe, incorporates the individual basins of the Guadalupe River and the San Antonio River above their confluence, portions of which are also in the 0.9-and-over class.

The 20 mapped areas on Figure 1 are those stream basins in which the municipal discharges are now receiving essentially "complete" treatment, and thus, by the philosophy of this study, are those in which conventional treatment could not compete with advanced waste treatment for further pollution control.

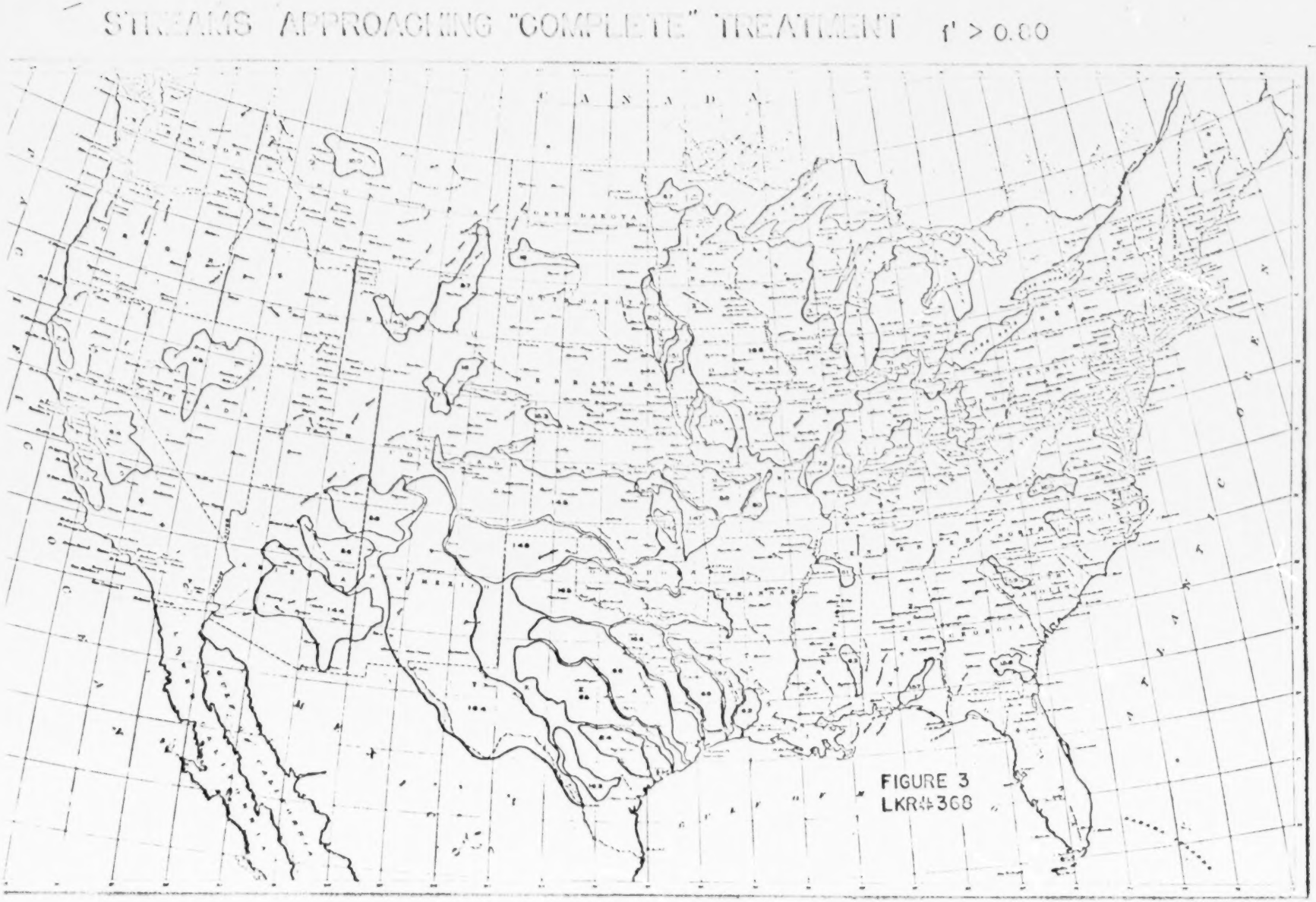
It is seen that only one of the 20 basins lies east of the Mississippi River. This should not be taken as a reflection on the pollution control activies east of the Mississippi River. From the standpoint of clean streams, it is quite possible that many streams in the East (as well as in the West) do not appear on the map, not because they have some untreated discharges or primary treatment, but simply because there are no municipal discharges at all to these streams. Also, most streams in the West where the population density is low have a comparatively small number of municipal discharges per stream and thus, the greater probability that these will approach "complete" treatment.

STREAMS APPROACHING "COMPLETE" TREATMENT f' > 0.90

FIGURE 1
LKR# 366

STREAMS APPROACHING "COMPLETE" TREATMENT $f' > 0.85$

FIGURE 2
LKR # 367


STREAMS APPROACHING "COMPLETE" TREATMENT r' > 0.60
C A N A D A
FIGURE 3
LKR-4368

Finally, the preponderance of mapped areas in the West cannot be directly related to advanced waste treatment markets, at least in terms of flow volume. As will be shown in a following paragraph, a major portion of the total discharge in the 0.90-and-over class comes from the one watershed east of the Mississippi, namely the Des Plaines River which takes the discharge from Chicago.

By Volume of Discharge

Table 4 shows the total non-duplicating recoverable discharge flow in each f - index range. In cumulating this figure, care was taken to exclude upstream tributaries so that their discharges would not be counted twice. The table shows the total discharge which, by the philosophy of this study, is not excluded from the potential AWT market at present. The volume of effluent for f above 0.90 is 1.48 bgd and for f above 0.85 is 2.23 bgd (this, of course, includes the 1.48 bgd from the higher f category). This 1.48 bgd is 14.5% of the nation's total municipal discharge reaching surface streams (excluding small coastal basins).

TABLE 4

TOTAL RECOVERABLE DISCHARGE BY f CATEGORY

f' **	Σ Q bgd*	% of Nation's Total Municipal Discharge	No. of Non-Duplicating Basins
> .90	1.48	14.5	20
> .85	2.23	21.9	38
> .80	3.51	34.5	53

* Recoverable discharge reaching streams

** f' is the weighted fraction removed including irrigation returns

Table 5 shows the total discharges of interest by region. It is seen that the 1.48 bgd in the $f \geq 0.9$ category is made up of 22.6% of the total municipal waste discharged to the western Gulf basins and 27.8% of the total municipal waste discharge to the Mississippi Basin. To be clear as to the meaning of these figures, for the Western Gulf region it means that of all the recoverable discharge reaching streams in the western Gulf region, 22.6% occurs to individual streams or stream-reaches for which f is 0.9 or over.

TABLE 5

TOTAL DISCHARGE BY f CATEGORY AND REGION

Region	mgd Total Waste	mgd f ≥ .9	%	mgd f > .85	%
Western Gulf	430.6741	97.3829	22.6	208.7687	48.5
Mississippi	4,913.2818	1365.2860	27.8	1,698.3825	34.6
Colo.-Calif. Column	449.1931	20.2617	4.5	82.3166	18.3
East-South	2,655.4286	0	0	9.9225	.37
Great Lakes	1,694.6575	0	0	176.1373	10.4
TOTAL*	10,170.6206*	1.48 bgd*	14.5	2.23 bgd*	21.9*

* Total includes slight additional from Red River of the North and excludes small coastal basins

By Major Contribution Cities

A special study was made of the 7 accumulation points in the nation above f = 0.80 which had cumulative discharges above 100 mgd. This analysis was made to determine the extent to which such discharges came from individual cities. The results are shown in Table 6. It is seen that, at least for these 100-mgd-and-over accumulation points, a relatively few cities make up the major portion of the total discharge.

Of the 1.48 bgd in the f = 0.9-and-over category in Table 4, the city of Chicago contributes 1.26 bgd or about 85 percent. The next largest individual city contributor in this 0.9-and-over class is San Antonio with a discharge of 70 mgd.

CONCLUSIONS

It may be concluded, under the philosophy of the present study, that to attain at present a higher degree of pollution control for the vast majority of the nation's streams, recourse would be made to extending the application of conventional treatment rather than to the application of advanced waste treatment. However, for a small percentage of the nation's streams (100 miles long and over), the municipal waste discharges thereto already receive as high a degree of treatment as can be

TABLE 6

MAJOR CONTRIBUTING CITIES

Accumulation Point, City	Q, mgd f > 0.8	No. of Major Cities	% of Total Discharge From Major Cities
Arkansas BCW Cimarron	122.5	3	43.2
Colo. Springs	6.5		
Pueblo	16.0		
Wichita	30.4		
White ACW Wabash	174.6	2	66.8
Indianapolis	96.8		
Muncie	20.0		
Trinity at Gulf	151.9	2	78.0
Forth Worth	37.4		
Dallas	81.0		
Scioto ACW Ohio	102.2	1	80.2
Columbus	82.0		
Maumee at Lake Erie	115.3	2	80.3
Fort Wayne	24.9		
Toledo	55.4		
Mississippi BCW Illinois	2021.1		
Chicago	1263.2	1	62.5
Waterloo	21.0		
Des Moines	16.7		
Cedar Rapids	13.0		
Davenport	12.0		
Minneapolis	145.0	9	12.6
Kenosha	15.4		
Madison	22.0		
Meenah	10.0		
Racine	19.5		

reached with conventional means. For these streams, over 4% of all U. S. streams, the next step in achieving a higher degree of pollution source control would be advanced waste treatment. The total discharge involved is 1.48 bgd or about 15% of the national total recoverable discharge; 1.26 bgd of this flows from the single city of Chicago. If an accumulated fraction BOD removed of 0.85 rather than 0.90 is taken as appropriate for the imminent potential application of advanced waste treatment, then the percentage of U. S. streams involved would be over 11% and the discharge about 2.2 bgd (about 22% of the nation's total recoverable discharge).

The reader is cautioned that there are many other factors that enter into the determination of the market for advanced waste treatment. Prominent among these, of course, is the total cost of advanced waste treatment as compared with the benefits to be achieved by the higher degree of pollution control. Benefits are also achieved in advanced waste treatment by augmentation of water supply, but the above analysis is concerned only with the pollution control aspect as a determinant of the market.

CHAPTER 4

UPSTREAM MUNICIPAL WASTES IN SURFACE WATER SOURCES

INTRODUCTION

The literature in recent years is found to contain a number of references to the higher degree of reuse of water in various river basins and to the increasing degree of reuse which the future must bring. Statements frequently quoted but difficult to track to their original source are that the Ohio River is reused six times at periods of low-flow and the Verdigris River in Kansas is reused 17 times from source to mouth. Such figures are obtained by taking the total withdrawal from the river and dividing it by some minimum stream flow figure. Thus, in the above quotations, the ratio of total water withdrawn to minimum stream flow would be six and 17 respectively.

The two major purposes of withdrawals in the nation are for irrigation and for industrial purposes, the former predominating in the West, the latter in the East. Of the total industrial withdrawals, something like three-quarters is for cooling, which for the most part returns water to the stream with very little degradation in quality.

The six-fold figure for the Ohio River has recently been adequately controverted by the actual data which show that at Cincinnati, the ratio of cumulative upstream withdrawals for all municipal or industrial uses except cooling to the drought flow is about 0.16 (2). When the withdrawals for cooling are included, the ratio becomes

2.71 at Cincinnati. In this case the drought flow is defined as that likely to occur one month out of 120 months, which, for the Ohio River, is about 10% of the average flow.

Such figures and such studies are of interest in advanced waste treatment for two reasons. First, advanced waste treatment in its ultimate application contemplates direct reuse of municipal or industrial waste waters. The impetus to advanced waste treatment in its pollution control aspects arises from the known facts that a certain degree of reuse now occurs, that the degree of reuse will inevitably increase in the future, and that conventional treatment processes do not remove all of the contaminants prior to voluntary or involuntary, recognized or unrecognized reuse. Thus, it is of interest to know the present degree and extent to which surface waters contain used waters from upstream.

Second, it is felt that there will be some psychological barrier, in the minds of the public at least, toward direct reuse of municipal waste water even though the water profession can demonstrate that the advanced waste treatment product constitutes C. P. H_2O. The public does not recognize, in general, and indeed, in general, it has not been known, how much upstream municipal wastes occur in river waters used for downstream municipal supplies. If this fraction is large, or even if in the minds of the public it is small and yet of general occurrence, such a fact could become a psychological advantage rather than a psychological obstacle. For in that case, the public would have two choices: either to drink used water which has been deliberately processed by advanced techniques to remove all contaminants, or to drink used water from which it is known that conventional processess cannot remove all the contaminants and which, in the face of this knowledge, has been placed in the river somewhere upstream with only the hope that nature will take care of it.

With these purposes in mind, including both the technical and the psychological aspects, the studies outlined in this Chapter were undertaken in order to determine just how much upstream municipal waste discharges generally are to be found in the surface water supply of cities.

It should be clearly recognized that unlike the studies or quotations previously referred to, the present study is concerned only with the municipal waste discharges upstream. Industrial waste discharges were not included partly because they do not play a great part in the psychological hurdle, but mostly because data on industrial waste discharges are not readily available. Nationwide, industrial withdrawal is about 14 times municipal withdrawal and approximately the same ratio should apply to the waste discharges including industrial cooling water.

This ratio, of course, does not hold for each individual stream but, on the average, the percentage of total upstream used water will be about 15 times those here reported for upstream municipal waste waters.

It should also be recognized that there is a difference between the reuse factors mentioned in this introduction and the data developed by the present study. The "reuse factors" conventinally used are not precisely reuse factors because they refer to the total amount of water withdrawn rather than the total amount returned to the stream. Obviously reuse must be measured by the water returned to the stream and is not influenced by water which is not returned to the stream. For a uniform type of use, e.g. irrigation or municipal having a constant return ratio, that is, ratio of water returned to water withdrawn, the true (return) reuse factor will be the withdrawal "reuse factor" times the return ratio. Thus for a stream involving only municipal discharges where the return ratio is of the order of 0.8 the return reuse factor will be 80% of the withdrawal "reuse factor". On an over-all average the return ratio for industrial use is also about 0.8 so this ratio would apply for combined industrial and municipal use along a stream. However, if the withdrawal is largely for irrigation purposes then the return ratio will be of the order of 0.2 and in that case the return reuse factor will be only 20% of the withdrawal "reuse factor". The above relations apply regardless of the number of actual withdrawal points and regardless of any natural increments to the stream in the reach under consideration.

METHOD

The detailed procedures by which the data were collected and handled are described in Chapter 6. There were selected for study approximately 160 municipalities of over 25,000 population and having a surface water source. The average stream flow in the water year 1961 (Oct 1960-Sept 1961) past the intake was determined from gaging station records and as the low-flow there was taken the flow for minimum flow month in that year. This low-flow is, in general, higher than commonly used figures for "drought flow". The concept of "drought flow" is arbitrary, both with regard to the drought duration, i.e., whether the minimum day, the minimum week, the minimum month, etc. and also with regard to recurrence interval, i.e. whether the indicated drought is to be expected once in 10 years, once in 100 years, etc. It is felt that the minimum flow month in 1961 is realistic in that the available municipal discharge figures used also apply to 1961 (although for the calendar year rather than the water year); thus the percentages computed show the actual percentages for the average flow for 1961 and for the minimum monthly flow for 1961. It is, of course, recognized that not only the stream flow, but also the municipal discharges have a seasonal variation, but the extent of this seasonal variation is not known and could not be incorporated in this national study.

The average annual cumulated upstream municipal waste discharges were obtained for each of the selected cities by the methods described in Chapter 6. The fractions computed were the ratios of these cumulative upstream discharges to the 1961 average flow and to the 1961 minimum month flow at each city's intake.

It is recognized also that there is a telescoping effect which is not taken into account in the present study, partly because the definition thereof is very difficult and partly again because the data are not available. To explain, the waste discharged by an upstream city is mixed with the stream flow before that stream flow is picked up by the next downstream city. Thus, the discharge from the second city includes some water which has already been discharged by the first upstream city. Some of the individual molecules of water in the discharge from the second city, therefore, have already been counted as discharge from the upstream city. The total amount of water that has been through one or more sewage systems upstream is, thus somewhat less than the sum of the discharges here reported. In effect, the present procedure weights the correct non-duplicating sum by the number of uses and reuses upstream. In terms of the contaminants carried by the discharges, therefore, the present procedure is a preferable measure. However, to avoid misunderstanding it should be clearly understood that the waste volumes here used are the sums of the upstream discharges.

RESULTS

Table 7 shows the results of the selected cities. The gaging station used in the computation and its approximate distance from the center of the city 's river front are shown.

By Population Served

Figure 4 shows the distribution of population served in the selected cities according to the percent of upstream municipal discharges present in the low-flow. It should be emphasized that these totals for population served are not the totals for the nation, but only for the sample. The sample consisted only of cities of over 25,000. Furthermore, there are 414 such U. S. cities having surface water supplies but only 155 of these were eligible for the sample in the sense of having the necessary data available.

In 1958, the population served by surface sources in cities under 25,000 was 13.5 million and in cities over 25,000 was 61.9 million (3). In 1962, the population served by surface water in cities over 25,000 remained at 61.9 million; the total population served in the sample of 155 cities, however, is only 21.1 million(4). The sample thus includes 38% of the cities of over 25,000 having surface water supplies and 34% of the population served in such cities.

TABLE 7
FRACTION OF UPSTREAM MUNICIPAL DISCHARGES IN MUNICIPAL SOURCES

Entry	Name of City	State	Source River	Gaging Station	Distance gaging station to city (straight line miles)	Cumulative municipal discharges (mgd)	Percent municipal waste in water supply: in low flow	Percent municipal waste in water supply: in avg. flow	Pop. Served
1	Topeka	Kan	Kansas	Kansas R. at Topeka	0	44.8081	4.16	.938	135,000
2	Lawrence	Kan	Kansas	Kansas R. at Lecompton	11	45.4691	4.04	.837	29,000
3	St. Joseph	Mo	Missouri	Missouri R. at St. Joseph	0	116.4101	4.49	2.00	92,000
4	Kansas City	Mo	Missouri	Missouri R. at Kansas City	0	671.3348	6.59	2.36	650,000
5	Jefferson City	Mo	Missouri	Mo. R. at Boonville & Saline Cr.	35	674.7828	5.73	1.80	32,000
6	St. Cloud	Minn	Mississippi	Mississippi near Royalton (1)	24	10.4920	1.94	.781	34,000
7	Minneapolis	Minn	Mississippi	Mississippi R. near Anoka	5	13.4040	1.35	.659	570,000
8	Ft. Collins	Colo	Cache La Poudre	Cache La Poudre R. near Ft. Collins(4)	5	.462	2.85	.191	25,027
9	Greely	Colo	Cache La Poudre	Cache La Poudre R. near Ft. Collins(4)	5	.462	2.85	.191	40,000
10	Denver	Colo	S. Platte	S. Platte R. at Denver	0	10.9674	21.4	6.59	612,000(5)
11	Englewood	Colo	S. Platte	S. Platte R. at Denver	5	4.2650	8.29	2.56	38,000
12	Bismarck	N.D.	Missouri	Missouri R. at Bismarck	0	65.3420	1.08	.629	27,670
13	Council Bluffs	Ia	Missouri	Missouri R. at Omaha, Neb.	7	187.7736	2.90	1.28	55,000
14	Omaha	Neb	Missouri	Missouri R. at Omaha	0	48.4088	2.29	1.01	335,000
15	Great Falls	Mont	Missouri	Missouri R. near Great Falls	10	12.7178	.558	.420	68,000
16	Billings	Mont	Yellowstone	Yellowstone R. at Billings	0	3.5631	.382	.122	62,300
17	Bartlesville	Okla	Caney at Hulah Caney at Bart.	Caney at Hulah (2) Caney at Oche Lata	14 8	.0778 .7788	1.03 3.21	.0178 .0682	32,000
18	Joplin	Mo	Shoal Cr.	Shoal Cr. above Joplin	4	.8090	1.49	.322	46,300
19	Ft. Smith	Ark	Clear Cr.	(3)	-	0	0	0	87,000
20	Muskogee	Okla	Neosho	Neosho near Ft. Gibson Res.	1	29.6688	3.30	.344	44,000
21	Pueblo	Colo	Arkansas	Arkansas R. near Pueblo	7.5	6.0180	4.26	1.60	115,000
22	Farmington	N.M.	Animas	Animas R. at Farmington	0	2.389	1.75	.547	25,000
23	Tacoma	Wash	Green	Green R. at Tukwila	12	.1840	.121	.0155	170,000
24	Everett	Wash	Sultan	Sultan R. near Startup	20	.2240	.330	.0387	66,500
25	Longview	Wash	Cowlitz	Cowlitz R. at Castle Rock (1)	6	.3620	.0248	.00465	29,600
26	Portland	Ore	Bull Run	Bull Run R. near Bull Run	0(6)	.2140	.391	.0341	560,582
27	Salem	Ore	N. Santiam	N. Santiam R. at Mehama	19	.0195	.00234	.00076	56,926
28	Eugene	Ore	McKenzie	McKenzie R. near Coburg	3	0	0	0	71,000
29	Santa Rosa	Calif	Russian	Russian R. near Guerneville	9	0	0	0	37,200
30	San Angelo	Tex	Concho	Concho R. near San Angelo	2	.2260	7.36	.732	60,500
31	Austin	Tex	Colorado	Colorado R. at Austin	0	11.4014	2.96	.707	216,000
32	Beaumont	Tex	Neches	Neches at Evadale (1)	21	10.4030	.823	.133	123,000
33	Shreveport	La	Cross Lake	PawPaw Bayou near Greenwood(4)	15	.0140	.946	.0111	185,000
34	Grand Forks	N.D.	Red	Red R. North of Grand Forks	0	13.133	6.02	1.72	34,000
35	Fargo	N.D.	Red	Red R. North of Fargo	0	3.952	6.60	1.86	46,000
36	Kansas City	Kan	Missouri	Missouri R. at Kansas City	0	197.8632	4.88	1.75	128,840
37	Minot	N.D.	Souris	Souris R. above Minot	3.5	.2910	4.03	1.74	30,000
38	Helena	Mont	Ten Mile Cr.	Ten Mile Cr. near Rimini	17	0	0	0	25,000
39	Eureka	Calif	Mad	Mad R. near Arcata	11	.0816	.423	.0093	28,000
40	Danville	Va	Dan	Dan R. at Danville	0	8.9332	1.60	.592	50,000
41	Highpoint	N.C.	Deep	(3)		0	0	0	29,500
42	Greensboro	N.C.	Reedy Fork Cr.	Reedy Fork Cr. near Gibonville	15	.0516	.341	.0808	125,000
43	Burlington	N.C.	Haw River Stoney Cr.	Haw River at Haw River (2) (3)	7 -	14.0160 0	15.1 0	4.23 0	32,000 -
44	Goldsboro	N.C.	Little	Little R. near Princeton	15	.5980	1.77	.333	30,000

Continued on Page 28

No.	Name of City	State	Source River	Gaging Station	Distance gaging station to city (straight line miles)	Cumulative municipal discharges (mgd)	Percent municipal waste in water supply: in low flow	Percent municipal waste in water supply: in avg. flow	Pop. Served
45	Wilson	N. C.	Contenea	Contenea R. near Hookerton	30	.1238	.150	.0232	31,000
46	Rocky Mount	N. C.	Tar	Tar R. near Nashville	5	2.9158	2.68	.618	34,000
47	Wilmington	N. C.	Cape Fear	NE Cape Fear R. near Chinguapin(1)	38	56.1027	4.05	1.22	55,000
48	Charlotte	N. C.	Catawba	Catawba R. at Catawba, S. C.	21	38.2951	4.31	2.48	215,000
49	Rockhill	S. C.	Catawba	Catawba R. near Rockhill	5	23.4423	1.49	.832	38,000
50	Greenville	S. C.	Saluda	Saluda R. near Greenville	4.6	.6810	.214	.133	175,000
51	Columbia	S. C.	Broad	Broad R. at Richtex	15	12.7136	.595	.284	165,000
52	Anderson	S. C.	Rocky & Black	Rocky R. near Calhoun Falls (3)	28	0	0	0	45,000
53	Augusta	Ga	Savannah	Savannah R. at Augusta	0	11.9271	.315	.208	160,000
54	Macon	Ga	Ocmulgee	Ocmulgee R. at Macon	0	11.5028	2.06	.569	120,000
55	Tampa	Fla	Hillsborough	Hillsborough R. near Tampa	5.5	7.2600	2.31	.522	285,000
56	Atlanta	Ga	Chattahoochee	Chattahoochee R. near Atlanta	0	5.6324	.555	.298	610,000
57	La Grange	Ga	Chattahoochee	Chattahoochee R. at W. Point	19	97.1900	4.94	2.43	25,000
58	East Point	Ga	Sweetwater Cr.	Sweetwater Cr. near Austell	6	.2250	.322	.0853	44,235
59	Columbus	Ga	Chattahoochee	Chattahoochee R. at Columbus	0	104.1980	4.55	2.03	150,000
60	Rome	Ga	Oostanawla	Oostanawla R. near Rome	4.5	1.0103	.157	.0434	50,000
61	Anniston	Ala	Coldwater Sp.	Coldwater Springs near Anniston	7	0	0	0	55,000
62	Gadsden	Ala	Coosa	Coosa R. at Gadsden	0	10.3041	.491	.158	80,000
63	Jackson	Miss	Pearl	Pearl R. at Jackson	0	3.5610	1.46	.127	144,422
64	Vicksburg	Miss	Mississippi	Mississippi R. near Vicksburg	1	4708.7855	3.39	1.25	32,000
65	Little Rock	Ark	Arkansas	Arkansas R. at Little Rock	0	289.0547	3.89	.829	220,000
66	Louisville	Ky	Ohio	Ohio R. at Louisville	0	759.9974	7.73	.969	115,487
67	Evansville	Ind	Ohio	Ohio R. at Evansville	0	857.0801	7.64	.908	155,000
68	Bowling Green	Ky	Barren	Barren R. at Bowling Green	0	3.4510	2.77	.226	33,000
69	Nashville	Tenn	Cumberland	Cumberland R. below Old Hickory(1)	12	16.8441	.338	.129	315,000
70	Lexington	Ky	Kentucky	Kentucky R. near Winchester	3	4.0221	2.04	.102	120,000
71	Charleston	W. Va	Elk-Kanawha	Kanawha R. at Charleston	0	19.7477	.933	.215	119,000
72	Cincinnati	Ohio	Ohio	Ohio R. at Cincinnati	0	561.2726	6.66	.845	825,000
73	Portsmouth	Ohio	Ohio	Ohio R. near Maysville, Ky.	45	420.1587	5.18	.693	60,000
74	Columbus	Ohio	Scioto	Scioto R. at Columbus	0	4.7322	5.39	.546	593,964
75	Huntington	W. Va	Ohio	Ohio R. at Huntington	0	398.7398	2.73	.804	118,092
76	Ashland	Ky	Ohio	Ohio R. at Ashland	0	411.4957	1.26	.177	45,000
77	Oak Ridge	Tenn	Clinch	Clinch R. near Searboro	3	15.3222	.876	.530	28,000
78	Chattanooga	Tenn	Tennessee	Tennessee R. at Chattanooga	0	101.0961	.643	.446	225,000
79	Kingsport	Tenn	Holston	S. Fork Holston at Kingsport	0	20.2786	2.36	1.37	45,000
80	Knoxville	Tenn	Tennessee	Tennessee R. at Knoxville	0	43.6017	.798	.496	175,000
81	Ft. Wayne	Ind	St. Joseph	St. Joseph R. at Cedarville	10	4.2833	9.78	1.39	189,000
82	Appleton	Wis	Fox	Fox R. at Rapide Croche Dam	15	30.0338	2.14	1.10	48,000
83	Kirkwood	Mo	Meramec	Meramec R. near Eureka	11	2.2010	.676	.101	25,000
84	St. Louis	Mo	Mississippi	Mississippi R. at St. Louis Missouri R. at Herman	0 49	750.6315 723.1173	7.04 5.02	2.56 1.41	870,000
85	Kankakee	Ill	Kankakee	Kankakee R. at Momonee (1)	10	11.3122	2.12	.651	52,000
86	Cedar Rapids	Iowa	Cedar	Cedar R. at Cedar Rapids	0	38.6992	6.97	1.64	90,000
87	Iowa City	Iowa	Iowa	Iowa R. at Iowa City	0	20.4398	10.7	1.83	37,000
88	Ottumwa	Iowa	Des Moines	Des Moines R. at Ottumwa	0	39.6893	11.2	1.11	39,000
89	Burlington	Iowa	Mississippi	Mississippi R. at Keokuk	—	481.4735	2.82	1.38	35,400

Continued on Page 29

Entry	Name of City	State	Source River	Gaging Station	Distance gaging station to city (straight line miles)	Cumulative municipal discharges (mgd)	Percent municipal waste in water supply		Pop. Served
							in low flow	in avg. flow	
90	Davenport	Iowa	Mississippi	Mississippi at Clinton (1)	25	311.6381	2.56	1.27	104,000
91	St. Paul	Minn	Mississippi	Mississippi R. near Anoka	5	184.0915	18.5	9.05	350,000
92	Hagerstown	Md	Potomac	Potomac R. at Hancock	25	16.5314	4.11	.603	53,000
93	Rockville	Md	Potomac	Potomac R. near Wash, D.C.	5	52.3634	3.86	.688	25,000
94	Petersburg	Va	Appamatox	Appamatox R. near Petersburg	6	1.0469	.40	.126	50,000
95	Richmond	Va	James	James R. near Richmond	1	26.6079	2.00	.654	303,000
96	Akron	Ohio	Cuyahoga	Cuyahoga R. at Old Portage	6	0	0	0	330,000
97	Alliance	Ohio	Mahoning	Mahoning R. at Alliance	0	.8270	17.4	1.85	35,850
98	Newark	Ohio	Licking	Licking R. near Newark	3.5	.8280	2.12	.234	45,500
99	Ann Arbor	Mich	Huron	Huron R. at Ann Arbor	0	1.4300	1.39	.634	68,000
100	Flint	Mich	Flint	Flint R. near Flint	2	1.5906	2.48	.739	200,000
101	Grand Rapids	Mich	Grand Rapids	Grand Rapids R. at Grand Rapids	0	46.3729	6.28	3.31	200,000
102	Washington	Pa	Chartiers Cr.	Chartiers Cr. at Carnegie	18	.7350	2.41	.406	41,000
103	Beaver Falls	Pa	Beaver	Beaver R. at Beaver Falls	0	57.8522	16.6	2.96	35,000
104	Durham	N.C.	Michie Lake	Flat R. at Bahama (4)	6	.4200	2.03	.431	92,000
105	Bloomington	Ill	Lake Bloomington	Money Cr. near Towanda	8	0	0	0	40,000
106	Alton	Ill	Mississippi	Mississippi R. at Alton	0	2023.7228	8.76	3.74	62,675
107	Rock Island	Ill	Mississippi	Mississippi R. at Clinton Iowa (1)	27	311.6381	2.56	1.27	51,780
108	Moline	Ill	Mississippi	Mississippi R. at Clinton Iowa (1)	24	299.3881	2.46	1.22	42,000
109	Granite City	Ill	Mississippi	Mississippi R. at St. Louis, Mo.	4	2750.7075	7.04	2.56	65,000
110	Tulsa	Okla	Spavinaw Lake	Spavinaw Cr. near Row (4)	0(6)	.9010	-	.907	295,000
111	Providence	R.I.	N. Pawtuxet	Pawtuxet R. at Cranston	7	7.0700	8.56	2.20	383,134
112	Lawrence	Mass	Merrimack	Merrimack R. at Lowell	7	61.3088	5.10	1.39	70,933
113	Auburn	N.Y.	Owasco Lake	Owasco Lake outlet near Auburn (4)	4	.4910	5.32	.271	35,249
114	Rome	N.Y.	Fish Cr.	E. Branch Fish Cr. at Taberg	10	.3180	.589	.116	44,000
115	Watertown	N.Y.	Black	Black R. at Watertown	0	2.1938	.290	.115	38,000
116	Poughkeepsie	N.Y.	Hudson	Hudson R. at Green Island	78	131.8611	4.39	1.49	55,000
117	Baltimore	Md	Potapsco	Potapsco R. at Rollofield	9	.4460	1.83	.493	930,000
118	Binghampton	N.Y.	Susquehanna	Susquehanna R. at Vestal	6	6.2712	.839	.155	87,000
119	Niagara	N.Y.	Niagara	Niagara R. at Buffalo	14	1562.8312	1.34	.921	101,000
120	N. Tonawanda	N.Y.	Niagara	Niagara R. at Buffalo	10	1562.7620	1.34	.921	31,500
121	Tonawanda	N.Y.	Niagara	Niagara R. at Buffalo	4	1540.2520	1.32	1.17	100,000
122	Wilmington	Dela	Brandywine Cr.	Brandywine Cr. at Wilmington	0	3.7780	3.22	1.03	156,100
123	Easton	Pa	Delaware	Delaware R. at Reigelsville, N.J.	8	.7500	.0263	.0108	58,000
124	Pottstown	Pa	Schuylkill	Schuylkill R. at Pottstown	0	21.8750	5.21	1.94	32,000
125	Norristown	Pa	Schuylkill	Schuylkill R. at Philadelphia	14	33.4170	4.68	1.80	70,000
126	Trenton	N.J.	Delaware	Delaware R. at Trenton	0	4.5370	.166	.0651	180,000
127	Philadelphia	Pa	Schuylkill	Schuylkill R. at Philadelphia	0	40.8890	5.73	2.22	2,250,000
128	York	Pa	Codorus Cr.	Codorus Cr. near York	2	3.5065	6.63	1.95	108,750
129	Lancaster	Pa	Conestoga Susquehanna	Conestoga at Lancaster Susquehanna R. at Marietta	0 14	1.7820 177.3253	1.67 3.38	.614 .783	100,000

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Name	Name of City	State	Source River	Gaging Station	Distance gaging station to city (straight line miles)	Cumulative municipal discharges (mgd)	Percent municipal waste in water supply: in low flow	Percent municipal waste in water supply: in avg. flow	Pop. Served
130	Lebanon	Pa	Fishing & Suntown	Swatora Cr. at Harbor Tavern	9	.0600	.0481	.0140	50,000
131	Harrisburg	Pa	Clark Cr.	Clark Cr. near Carson	17	0	0	0	111,000
			Susquehanna	Susquehanna R. at Harrisburg	0	129.0753	3.12	.628	
132	Camphill	Pa	Yellow Breeches	Yellow Breeches Cr. near Camphill	1	1.4270	1.97	.778	55,000
133	Warren	Ohio	Mosquito Res.	Mosquito Cr. below Mosquito Cr. Dam(4)	6	0	0	0	70,000
134	Sharon	Pa	Shenango	Shenango R. at Sharpsville	4	2.0950	3.54	.566	58,500
135	New Kensington	Pa	Allegheny	Allegheny R. at Watrona	6	71.7301	7.36	.670	43,000
136	S. Pittsburgh	Pa	Monongahela	Monongahela R. at Braddock	8	44.6618	3.98	.501	47,600
137	Pittsburgh	Pa	Allegheny	Allegheny R. at Watrona	19	79.0341	4.76	.738	650,000
138	Steubenville	Ohio	Ohio	Ohio R. at Sewickley (1)	28	216.5764	9.08	.955	44,048
139	Weirton	W. Va	Ohio	Ohio R. at Sewickley Pa. (1)	28	215.9324	9.05	.952	32,832
140	Clarksburg	W. Va	W. Fork	West Fork R. at Clarksburg	0	.8321	2.60	.197	33,812
141	East Liverpool	Ohio	Ohio	Ohio R. at Sewickley (1)	21	211.2244	8.90	.936	28,638
142	Fairmount	W. Va	Tygart Valley	Tygart Valley R. at Colfax	6	2.4759	.919	.124	51,148
143	Morgantown	W. Va	Monongahela	Monongahela R. at Lock 15, Hoult	10	7.4701	1.90	.248	36,000
144	Phenix City	Ala	Chattahoochee	Chattahoochee R. at Columbus	5	104.2254	4.56	2.03	32,000
145	Decatur	Ala	Tennessee	Tennessee R. at Whitesburg	27	122.4301	.589	.418	29,000
146	E. St. Louis	Ill	Mississippi	Mississippi R. at St. Louis, Mo.	1	2984.6865	7.64	2.77	170,000
147	New Albany	Ind	Ohio	Ohio R. at Louisville, Ky.	4	755.1984	7.69	.963	37,940
148	Terre Haute	Ind	Wabash	Wabash R. at Terre Haute	0	96.1437	10.6	1.47	81,000
149	Paducah	Ky	Ohio	Ohio R. at Matropolis, Ill.	8	1188.9046	2.32	.653	53,000
150	Newport	Ky	Ohio	Ohio at Cincinnati, Ohio	5	554.4430	6.57	.835	56,000
151	Covington	Ky	Ohio	Ohio R. at Cincinnati, Ohio	5	554.4430	6.57	.835	90,000
152	Bossier City	La	Red	Red R. at Shreveport	5	63.3741	1.07	.363	33,500
153	Monroe	La	Ouachita	Ouachita R. at Monroe	0	17.8100	.769	.142	65,000
154	Yakima	Wash	Naches	Naches R. near Naches	17	2.0311	.648	.155	13,800
155	Elmira	N.Y.	Chemung	Chemung R. at Chemung	9	5.7786	4.20	.347	70,000

(1) - Flow adjusted for tributary entering stream after gaging station and before city.

(2) - Two sources of supply.

(3) - Total waste flow is 0, thus percent is 0 regardless of flow in stream.

(4) - Lake or reservoir source. Low flow figure generally not applicable.

(5) - Population served not accurate for source given due to other sources used.

(6) - Distance between gaging station and pipeline intake.

No. on Map	Name of City	State	Source Basin	Gaging Station	Distance gaging station to city (straight line miles)	Cumulative municipal discharges (mgd)	Percent municipal waste in water supply: in low flow	Percent municipal waste in water supply: in avg. flow	Pop. Served
130	Lebanon	Pa	Fishing & Suntown	Swatora Cr. at Harbor Tavern	9	.0600	.0481	.0140	50,000
131	Harrisburg	Pa	Clark Cr.	Clark Cr. near Carson	17	0	0	0	111,000
			Susquehanna	Susquehanna R. at Harrisburg	0	129.0753	3.12	.628	
132	Camphill	Pa	Yellow Breeches	Yellow Breeches Cr. near Camphill	1	1.4270	1.97	.778	55,000
133	Warren	Ohio	Mosquito Res.	Mosquito Cr. below Mosquito Cr. Dam(4)6		0	0	0	70,000
134	Sharon	Pa	Shenango	Shenango R. at Sharpsville	4	2.0950	3.54	.566	58,500
135	New Kensington	Pa	Allegheny	Allegheny R. at Watrona	6	71.7301	7.36	.670	43,000
136	S. Pittsburgh	Pa	Monongahela	Monongahela R. at Braddock	8	44.6618	3.98	.501	47,600
137	Pittsburgh	Pa	Allegheny	Allegheny R. at Watrona	19	79.0341	4.76	.738	650,000
138	Steubenville	Ohio	Ohio	Ohio R. at Sewickley (1)	28	216.5764	9.08	.955	44,048
139	Weirton	W.Va	Ohio	Ohio R. at Sewickley Pa. (1)	28	215.9324	9.05	.952	32,832
140	Clarksburg	W.Va	W. Fork	West Fork R. at Clarksburg	0	.8321	2.60	.197	33,812
141	East Liverpool	Ohio	Ohio	Ohio R. at Sewickley (1)	21	211.2244	8.90	.936	28,638
142	Fairmount	W.Va	Tygart Valley	Tygart Valley R. at Colfax	6	2.4759	.919	.124	51,148
143	Morgantown	W.Va	Monongahela	Monongahela R. at Lock 15, Hoult	10	7.4701	1.90	.248	36,000
144	Phenix City	Ala	Chattahoochee	Chattahoochee R. at Columbus	5	104.2254	4.56	2.03	32,000
145	Decatur	Ala	Tennessee	Tennessee R. at Whitesburg	27	122.4301	.589	.418	29,000
146	E. St. Louis	Ill	Mississippi	Mississippi R. at St. Louis, Mo.	1	2984.6865	7.64	2.77	170,000
147	New Albany	Ind	Ohio	Ohio R. at Louisville, Ky.	4	755.1984	7.69	.963	37,940
148	Terre Haute	Ind	Wabash	Wabash R. at Terre Haute	0	96.1437	10.6	1.47	81,000
149	Paducah	Ky	Ohio	Ohio R. at Matropolis, Ill.	8	1188.9046	2.32	.653	53,000
150	Newport	Ky	Ohio	Ohio at Cincinnati, Ohio	5	554.4430	6.57	.835	36,000
151	Covington	Ky	Ohio	Ohio R. at Cincinnati, Ohio	5	554.4430	6.57	.835	90,000
152	Bossier City	La	Red	Red R. at Shreveport	5	63.3741	1.07	.363	35,500
153	Monroe	La	Ouachita	Ouachita R. at Monroe	0	17.8100	.769	.142	65,000
154	Yakima	Wash	Naches	Naches R. near Naches	17	2.0311	.648	.155	13,800
155	Elmira	N.Y.	Chemung	Chemung R. at Chemung	9	5.7786	4.20	.347	70,000

(1) - Flow adjusted for tributary entering stream after gaging station and before city.

(2) - Two sources of supply.

(3) - Total waste flow is 0, thus percent is 0 regardless of flow in stream.

(4) - Lake or reservoir source. Low flow figure generally not applicable.

(5) - Population served not accurate for source given due to other sources used.

(6) - Distance between gaging station and pipeline intake.

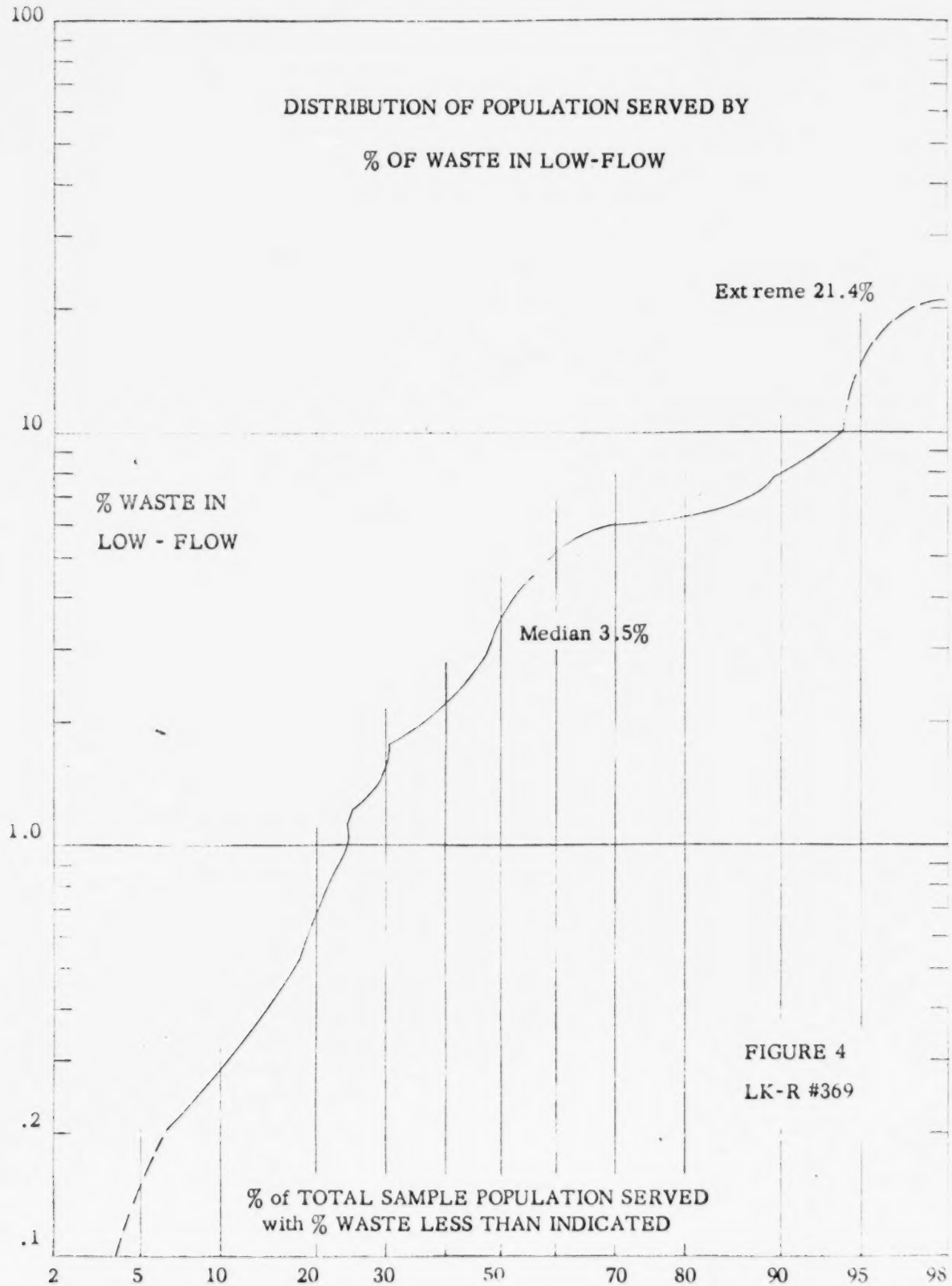

FIGURE 4

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It is seen from Figure 4 that the median for the study sample is 3.5% upstream municipal waste in the low-flow past the intake. This means that in the sample of 155 cities having a total population of 21.1 million, for 50% of that population or 10.5 million people, the percent municipal discharge in the low-flow was greater than 3.5% and for the other 50%, it was less than 3.5%. For about 6% of the population served, the percent municipal waste water in the low-flow was over 10%. In simple terms, the figure of 3.5% signifies that for the median population of every 30 gallons of water flowing through its intake during the low-flow month of 1961, 1 gallon was water that had passed through a municipal sewer system upstream.

Figure 5 shows a similar frequency distribution by number of cities rather than by population served. The median here is 2.40% and about 4.5% of the cities have an amount of municipal waste in their low-flow greater than 10%.

This study does not directly investigate the degree of treatment which the 1 gallon of waste water had received. It may have received no treatment at all, in which case the 1 gallon represents the equivalent of the waste materials that were present in one gallon of the raw sewage. At the other extreme, it may have received "complete" treatment (i.e., a 90% BOD removal), in which case the 1 gallon represents the inorganic wastes in 1 gallon of sewage and the organic wastes in 0.1 gallon of sewage. In contemplating this simplification, it should be remembered that the organics present in the completely treated effluent are not identical with those present in the raw sewage, the nominal 0.9 removal efficiency representing a selective removal of those organics which are amenable to conventional treatment.

CONCLUSIONS

Based on a sample representing 38% of the U. S. cities having a surface water supply and 34% of the population served by these cities, the range of upstream municipal waste water present in the low-flow past water supply intakes is from 0% to over 20% with a median based on the number of cities at 2.40% and based on population served at 3.5%. This means that for the median population, each 30 gallons of water flowing through the intake during the low flow month contains 1 gallon of water which has passed through the sewage system of an upstream community.

If the national average ratio of industrial to municipal water withdrawals (approximately 14:1) should be considered as applying to waste ratios present at each municipal intake, the median reuse factor, including both municipal and industrial water, would be of the order of 0.5 and, for the worst cases in the sample, of the order of 3.0.

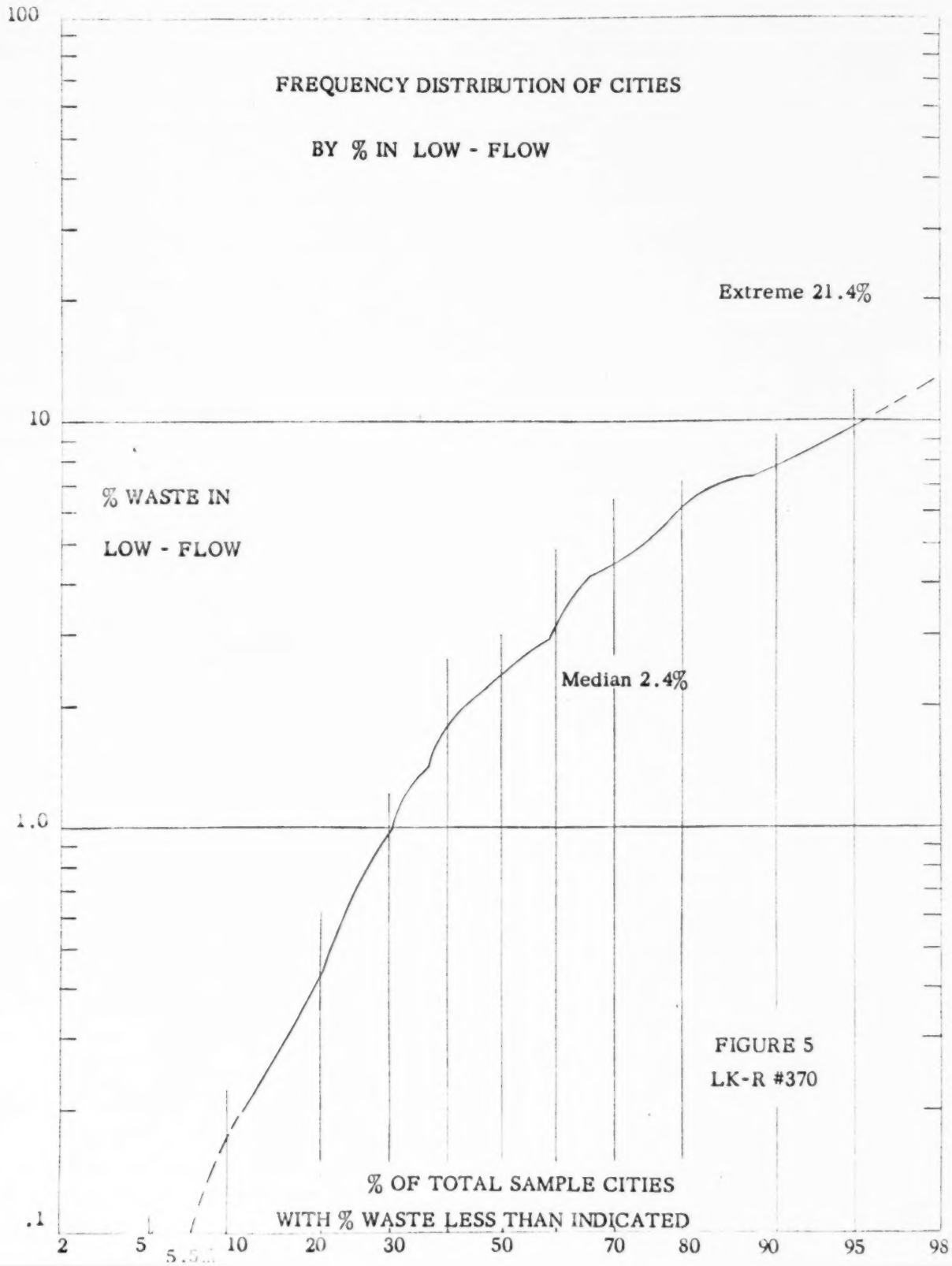

FIGURE 5
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CHAPTER 5

IMPACT OF ADVANCED WASTE TREATMENT ON THE NATIONAL ECONOMY

Introduction

Distribution of Sewage Flow by mgd Size

- Economic model for study

Consumptions in AWT by Distillation-Adsorption

- Unit consumptions in distillation
- Distillation adsorption unit consumptions
- Fuel
- Electric energy
- Chemicals

Consumptions in AWT by Adsorption-Electrodialysis

- Adsorption-electrodialysis Flow Sheet
- Fuel
- Electric Energy
- Chemicals

Ultimate Disposal by Incineration

Ultimate Disposal by Pipelining

- Trunk lines
- Optimum Grouping

Ultimate Disposal by Injection

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INTRODUCTION

It is desirable to explore the AWT concept for logistical imbalances in the national economy. The effect of advanced waste treatment on national life could potentially be great. However, in the present study there are explored only certain aspects of the consumptions of materials and services arising out of advanced waste treatment. The purpose is to determine whether widespread use of AWT might strain the economy by requiring exhorbitant quantities of certain resources or services. The resources explored in the present study are fuel, electric power, chemicals, and certain aspects of the ultimate disposal phase.

Distribution of Municipal Waste Flows by Volume

The unit consumptions of fuel, electric energy, etc. can sometimes be expected to vary, not only with type of process, but also with production rate or capability of the installation. In order to take this variation into account in summing the total national consumption of resources, it was necessary to know the distribution of waste flows by volume of individual installations.

To do this, data from the 1957 Inventory of Municipal Waste Facilities was utilized as summarized in Reference 1. (The corresponding statistical summary for the 1962 Inventory was not yet available at the time of writing). This reference provides data excerpted in Table 8 for the 11,131 sewered communities in the nation from the 1957 inventory. These data were manipulated according to the columns and notes of Table 8 to produce the cumulative frequency distribution shown in Columns 7, 8 and 9.

Of the total waste flow accumulated, about 13.8 bgd or 58.6%, was found in the single class of population served of greater than 100,000. In order to develop the the distribution for this large open-end class, use was made of the data on the water supply of the nation's 100 largest cities from Ref. 5. These data concern water use rather than sewage flow but for the present purposes, it was assumed that these are proportional. The 100 cities were tallied by population served category and the total in each class was summed to obtain Column 2. The smallest of the 100 cities had a population of 128,000 and, thus, the lowest size class did not start at 100,000, i.e., the cut-off point of the study in the top portion of Table 8. This was remedied by estimating the missing 100,000-128,000 class as described in Note 4. These adjusted figures indicated a population served of 62.281 million whereas the sewage flow study had only 52.309 million. A proportional adjustment was made as in Note 5. The average and class boundaries were computed by applicaton of the per capita flows, $\overline{PC}$'s, to the actual populations in the population class, not to the conventional class boundaries in Column 1.

The results shown in Column 9 are plotted in Figure 6 to give a cumulative frequency distribution of percent of the nation's total flow of municipal waste water produced in plants less than the indicated size. The indicated size of "plant" is expressed as flow (mgd) per community. Some communities, especially the larger ones, have more than one collection and/or treatment facility and, accordingly, the curve would be somewhat displaced downward, especially in the high flow range, if it were expressed in flow per facility.

The distribution curve passing through the top of each class indicates, for example, that 50% of the nation's municipal waste water production occurs from plant sizes less than 35 mgd. This is not to be confused with the frequency distribution for number of communities. The median, plant by number, would correspond to a much lower flow. Indeed as shown in Column 7, the average waste flow

TABLE 8

DISTRIBUTION OF U.S. MUNICIPAL WASTE WATER FLOWS BY VOLUME CATEGORY

1 Population Group (1000's)	2 Pop. Served (millions)	3 % of Sewered Communities	4 No. of Sewered Comm. (1)	5 PC Natl. (gpcd)(7)	6 Total Flow in Class (mgd)(2)	7 Avg. Flow (mgd/comm) (3)	8 Class Boundaries (mgd/comm)	9 Cumul Distn. of flows (% less than)
<0.5	0.368	11.3	1258	131	48	0.038	<0.066	0.35
0.5-1	1.207	17.6	1959	131	158	0.080	0.066-0.131	1.49
1-5	9.590	46.8	5209	131	1256	0.251	0.131-0.655	10.57
5-10	7.266	11.4	1269	131	952	0.750	0.655-1.31	17.45
10-25	11.128	8.0	890	120	1335	1.500	1.20 -3.00	27.10
25-50	8.044	2.7	300	120	965	3.218	3.00 -6.00	34.08
50-100	8.446	1.2	133	120	1013	7.620	6.00-1200	41.40
> 100	52.309	1.0	111	155	8108	73.044	> 15.5	100.00
TOTAL	98.361	100.0	11, 131		13, 836	1.243		
< 150	1.206		9			(5)		(6)
100-150 est.(4)	3.2		27	155		15.5	13.0-19.3	44.40
150-300	7.309		37	"		25.8	19.5-38.0	51.28
300-500	7.187		20	"		46.7	41.0-63.4	58.05
500-1000	14.294		22	"		84.6	65.1-112.8	71.50
1M-2M	7.972		6	"		172.9	130-218	79.00
2M-4M	9.539		4	"		310.3	260-401	87.98
>4M	12.773		2	"		831.4	576-1087	100.00
TOTAL	62.281		118					

(1) Col. 3 x total of 11, 131

(2) Col. 2 x Col. 5

(3) Col. 6 ÷ Col. 4

(4) The <150 class boundaries were 128-148. Estimate is based on the assumption that no. of communities in 100-128 class is 2 x no. in 128-150 class.

(5) Average population in class x 155 gpcd x 52.309/62.281

(6) Cumulative %'s of flow in >100 population classes were adjusted to total 58.60% which is the % over all classes represented by the >100 class from upper portion of Table

(7) From data in Chapter 6

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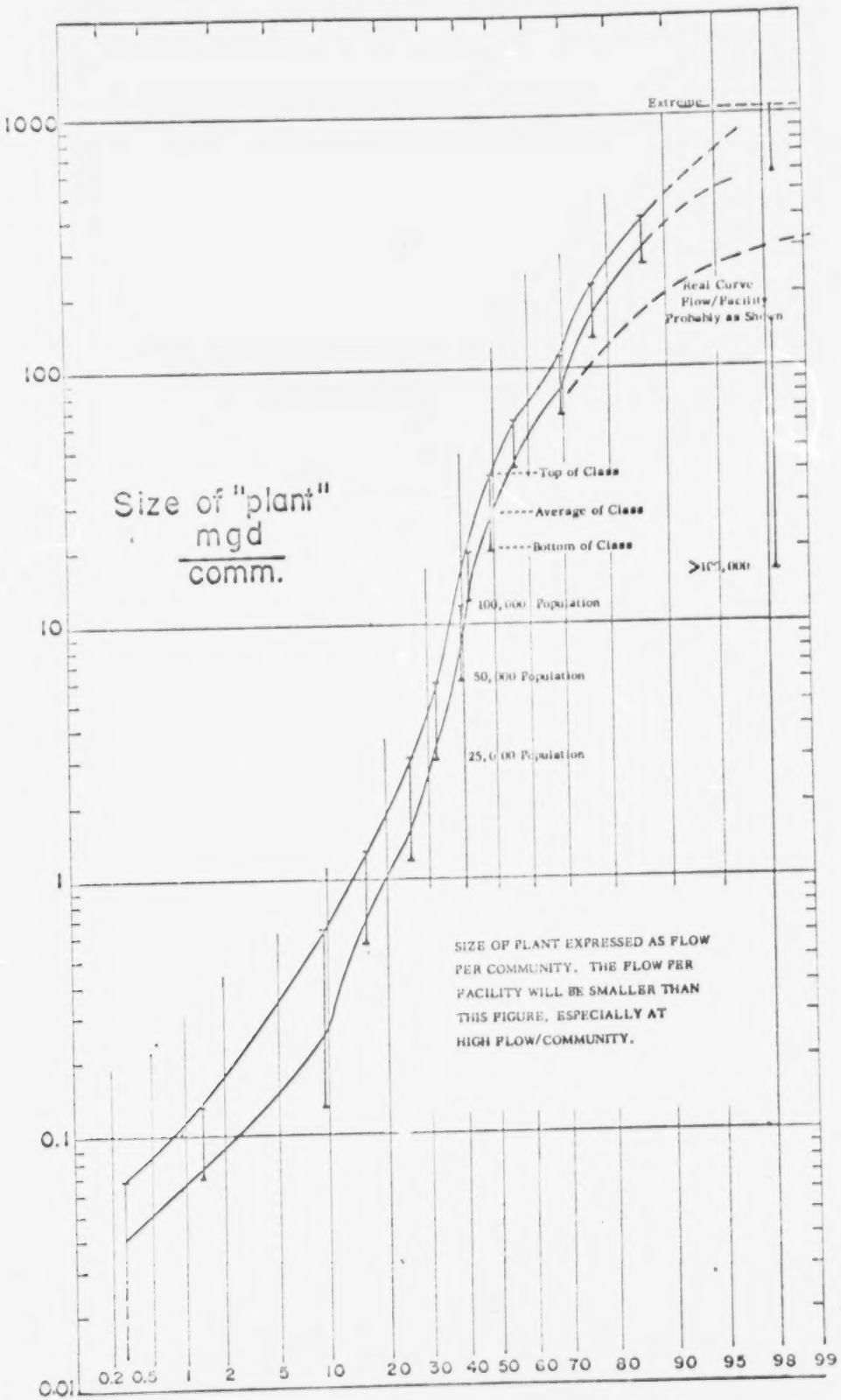
DISTRIBUTION of U.S. WASTE WATER FLOWS

By Size of Plant



per community is only about 1.24 mgd. Communities having waste flows greater than 100 mgd contribute about 32% of the total U. S. flow. Communities having flows less than about 4 mgd contribute another 30%.

Economic Model For Study

On the basis of Figure 6, there was chosen an economic model for study of the possible effect of AWT on the economy. The model consisted of the application of advanced waste treatment to each of the approximately 11,000 sewered communities now in existence and assumed a size distribution equal to the real distribution as read from Figure 6.

Certainly, by the time that advanced waste treatment would be applied on all sewered communities, the number of sewered communities and the population concerned would be greater than it is now. Thus, when and if the model becomes a reality, the amount of advanced waste treatment installed would be greater than here computed. However, the purpose of the study is to compare consumptions for advanced waste treatment with corresponding national consumptions and productions; this can best be done in terms of the current year or historical data rather than by extrapolating both sets of data into the indefinite future.

The characteristics of the model are as shown in Table 9.

TABLE 9

ECONOMIC MODEL OF AWT PLANTS

Size of Plant (mgd)	% of Total Flow	Total Flow Treated (mgd)
< 0.1	3	450
0.1-1.0	18	2700
1-10	23	3450
10-100	31	4650
100-800	25	3750
		15,000

The total waste flow of the model has been rounded to 15 bgd.

As will be shown in the next section, the first use of the model made it apparent that the consumptions relative to national productions were to be so small that the additional accuracy obtained by applying varying unit consumptions to the selected distribution would be of no significance.

CONSUMPTIONS IN AWT BY DISTILLATION-ADSORPTION SYSTEMS

Unit Consumptions in Distillation

Unit consumptions for distillation were obtained from recent work under the Advanced Waste Treatment Research Program (6, 7). The unit consumptions are shown in Table 10.

TABLE 10

UNIT CONSUMPTIONS BY DISTILLATION

Production (mgd)	0.1	1	10	100
Fuel, 1000 BTU/1000 gal EV feed	1230	690	750	600*
Power, KWH/1000 gal EV feed	0.7	0.7	0.7	0.7*
H_2SO_4, lbs 66°Be' acid/1000 gal EV feed**	2.2	2.2	2.2	2.2

* Estimated by LK-R

** U.S.P.H.S. estimate based on expected average HCO_3^- level

Unit Consumptions in Adsorption

An adsorption-distillation flow sheet for advanced waste treatment was developed in which part of the feed (waste water) is evaporated and part is treated with activated carbon. The following data supplied by the AWT Research Program represent the present estimates of carbon use in adsorption and organic carry-over in evaporator condensate. The evaporator condensate, assumed to have 5 ppm organic content, is also treated by adsorption. It is assumed that adsorption, in both cases, removes 90% of the organics and that a capacity of 0.3 lbs organic matter per lb. carbon is achieved in the main adsorber and 0.1 lbs organic per lb. carbon is reached in the condensate polisher. This amounts to a total doseage of 0.77 (say .8) pounds of carbon per thousand gallons when the feed contains 50 ppm organics. The carbon loss is predicted to be approximately 6% per regeneration cycle. The unit consumptions and flows are shown in Table 11.

Fuel

When the ratios in Table 11 are applied to the economic model and interpolated figures for fuel consumption per 1000 gallons are taken from Table 10, there results a total fuel consumption for the 15 bgd model of 6.6×10^{12} BTU/day. The total U. S. energy consumption

TABLE 11

UNIT CONSUMPTIONS BY ADSORPTION-DISTILLATION

Total Product water	0.947 gallons/gal AWT feed
Volume Evaporator feed	0.525 gal/gal AWT feed
Volume to Main Adsorber feed	0.475 gal/gal AWT feed
Volume Condensate	0.472 gal/gal AWT feed
Carbon makeup	0.048 lbs/1000 gal AWT feed
66^{o} Be' H_2SO_4	1.15 lbs/1000 gal AWT feed

in 1958 (8 and 9) was 113×10^{12} BTU/day. Accordingly, the fuel used for AWT by adsorption-distillation systems applied to all sewered communities corresponds to 5.8% of the nation's total energy use. The growth rate in national energy use is about 3% per year so that the AWT use corresponds to about 2 years' growth.

Electric Energy — In addition to the 0.7 KWH/1000 gal used in the evaporator section, some electric energy will be needed for pumping in the two adsorption stages. Pumping water through a 40 psi pressure drop requires about 0.4 KWH/1000 gal. It is, of course, unlikely that pressure drops as high as 40 psi would be encountered with granular carbon adsorbent so the estimate is conservatively high. The composite is 0.73 KWH/1000 gal of process feed which, applied to the model, gives 11.0×10^{6} KWH/day.

The total electrical generation of the nation (9) is about 2.7×10^{9} KWH/day so the electrical energy required for the AWT model is only 0.4% of the total electric generation.

Chemicals — The 2.2 pounds H_2SO_4 per 1000 gallons EV feed applied to the 15 bgd model gives a consumption of 8700 tons per day of 66^{o} Be' H_2SO_4. U. S. production of 100% equivalent H_2SO_4 in 1962 was 119.117×10^{6} tons(10) corresponding to 352,000 tons/day of 66^{o} Be' acid (93.2%). Thus the consumption for the model would be 2.5% of U. S. production.

The 0.048 pounds of carbon per thousand gallons calls for 360 tons per day of activated carbon. The total national production of activated carbon in 1962 was 169 tons per day (11). Thus, full-scale application of AWT by adsorption-distillation would increase the activated carbon consumption 113% over the present consumption.

However, the water and waste treatment industries together used 24,000 tons of activated carbon in 1957 (12) and one may estimate that this figure is approximately 28,000 tons in 1962, corresponding approximately to 74 tons per day. Even if this 74 tons per day were dispensed with by complete application by AWT, there still would remain a requirement for 286 tons per day which is still a 69% increase over the present production.

From the above computation, it is apparent that full-scale application of adsorption-distillation AWT would have little effect in fuel, electric energy, or sulfuric acid production, but would have a major effect on the activated carbon industry.

CONSUMPTIONS IN AWT BY ADSORPTION - ELECTRODIALYSIS SYSTEMS

Adsorption-Electrodialysis Flow-Sheet

An alternative likely AWT system is adsorption-electrodialysis. The basis is a flow-sheet in which adsorption is applied to all the feed followed by single stage electrodialysis. The feed organic concentration, carbon capacity, etc. are the same as those for the main adsorber of the adsorption-distillation flow-sheet and a carbon dose of 1.25 lbs/1000 gal. results. The final product will contain 400-500 ppm inorganics. Unit flows and consumptions for this flow sheet are shown in Table 12.

TABLE 12

UNIT CONSUMPTIONS BY ADSORPTION-ELECTRODIALYSIS

mg per mg Feed to Plant

Volume product water	0.95 gal/gal feed
Volume to adsorber	1.0 " " "
Volume to electrodialyzer	1.0 " " "
Carbon make-up	0.075 lbs/1000 gal. feed
H_2SO_4 required	1.2 lbs 66° Be′ acid/1000 gal.

Fuel

No significant amount of fuel is consumed in the adsorption-electrodialysis process.

Electric Energy

Electric energy for electrodialysis is estimated at 6 KWH/1000 gal. per stage including the pumping for that stage. In addition there will be required about 0.4 KWH/1000 gal. for pumping in the

adsorption stage. This totals 6.4 KWH/1000 gal feed, or for the nation, approximately 95×10^9 KWH/day. This is 3.5% of the current total U. S. electric energy generation.

Chemicals

The latest estimation (13) for H_2SO_4 requirements in adsorption-electrodialysis is 1.2 lbs. 66° Be' H_2SO_4/1000 gal. AWT feed. This is based on an average expected HCO_3^- content of 310 ppm in the AWT feed. Applied to the model the consumption would be 9000 tons/day or 2.6% of U. S. production.

The 0.075 lbs/1000 gal activated carbon make-up amounts to 560 tons of carbon per day which is 3.3 times the current production.

Electrodialysis Membranes

One component of electrodialysis equipment requires regular replacement and might be considered as "consumable materials". These are the membranes. According to latest estimates (13) a 10 mgd plant required 38,600 sq. feet of membrane. Thus plants for 15,000 mgd would require 58×10^6 sq. feet of membrane, or at an average life of 5 years 11.6×10^6 sq ft/yr replacement.

The electrodialysis industry is in its infancy so projections as to increases in present membrane production rates would be not significant. Furthermore present production rates are unknown.

However the total installed world capacity for electrodialysis probably does not exceed 3 mgd -- so application to the AWT model would involve a factor of the order of 5000.

In summary, for AWT by adsorption-electrodialysis, as for the adsorption-distillation, the effect on the economy in fuel, electric energy, and H_2SO_4 would be inconsequential, but the activated carbon production of the nation would have to be greatly expanded, as of course would the electrodialysis membrane industry.

ULTIMATE DISPOSAL BY INCINERATION

The incineration process taken for study will be that discussed in Reference 14. Case 2 from Table 2 of that reference will be used as a basis of computation since it uses the largest size of furnace unit. When Reference 14 was written, it was not clear just what might be the concentration of AWT waste and, accordingly, incineration was studied over the complete range of possible concentration. The development of the AWT research to the present, however, has suggested that AWT wastes probably will be quite highly concentrated; indeed, probably somewhere

between 15% and 30% total solids corresponding to 99.8-99.9% water recovery from an average secondary effluent. For that reason, in the present study the preconcentration steps will be dispensed with and it will be assumed that the AWT waste is the same as the 30% dry feed used in Reference 14.

The fuel consumption for the incinerator is 22×10^6 BTU/hr or 1.41×10^6 BTU/ton of solids in the feed. Since the feed comprises 104,650 lb/hr in the model 15 bgd of secondary effluent at 300 ppm contaminant content, there are 18,600 tons of contaminants per day produced in the model. Thus, the fuel for incineration would be 26.4×10^9 BTU/day or 0.02% of U. S. energy production.

At 792 (14) KW the electric energy consumption is 50.3 KWH/ton of solids in feed. The national total would be 94×10^4 KWH/day which is 0.03% of U. S. electric generation.

Applied strictly to the cases worked out in Reference 14, the 18,600 tons per day of contaminants would be reduced to 12,400 tons of inorganics after the incineration. The average haul to the ocean, not considering the non-uniform geographical distribution of sewered communities, would be approximately that from Kansas to the Gulf or about 700 miles. The railroad haulage then would amount to 8.7×10^6 ton miles per day. In 1962 the railroads hauled $600,200 \times 10^6$ ton miles of freight (15). Thus, the railroad haulage of the incinerated solids would amount to about 0.5% of the national railroad ton-mile haulage. Motor trucks in 1962 hauled $331,900 \times 10^6$ ton miles (15) so that the AWT haulage would amount to about 0.9% of the total truck ton-mile haulage.

In summary, for ultimate disposal by incineration, the impact on the economy in fuel, electric energy, and haulage would be quite inconsequential.

ULTIMATE DISPOSAL BY PIPELINING

Trunk Lines

Work on another project in the AWTR Program (16) indicates that the scale economy in pipelining is great enough to demand that communities form into groups or cells for the purpose of combining their ultimate disposal of AWT wastes by pipelining. It is too early to estimate how many combined trunk-lines might be economic for the nation if conveyance were to be the only disposal method. For the present, it will be assumed that there are 100 trunk-lines (i.e., about 2 per state) transporting waste concentrates to the nearest ocean. At 99.9% water recovery, the waste will amount to 15 mgd and, thus, the capability of the average pipeline would be about 0.15 mgd. At this flow rate, pipelining is economic over rail tank-car or highway tank-truck at all distances.

The unit utilization of energy in pipelining is shown in Figure 7, from whence it is seen that for horizontal pipelining, the energy requirement is maximum in the neighborhood of 0.4 mgd capability and this maximum is at approximately 0.025

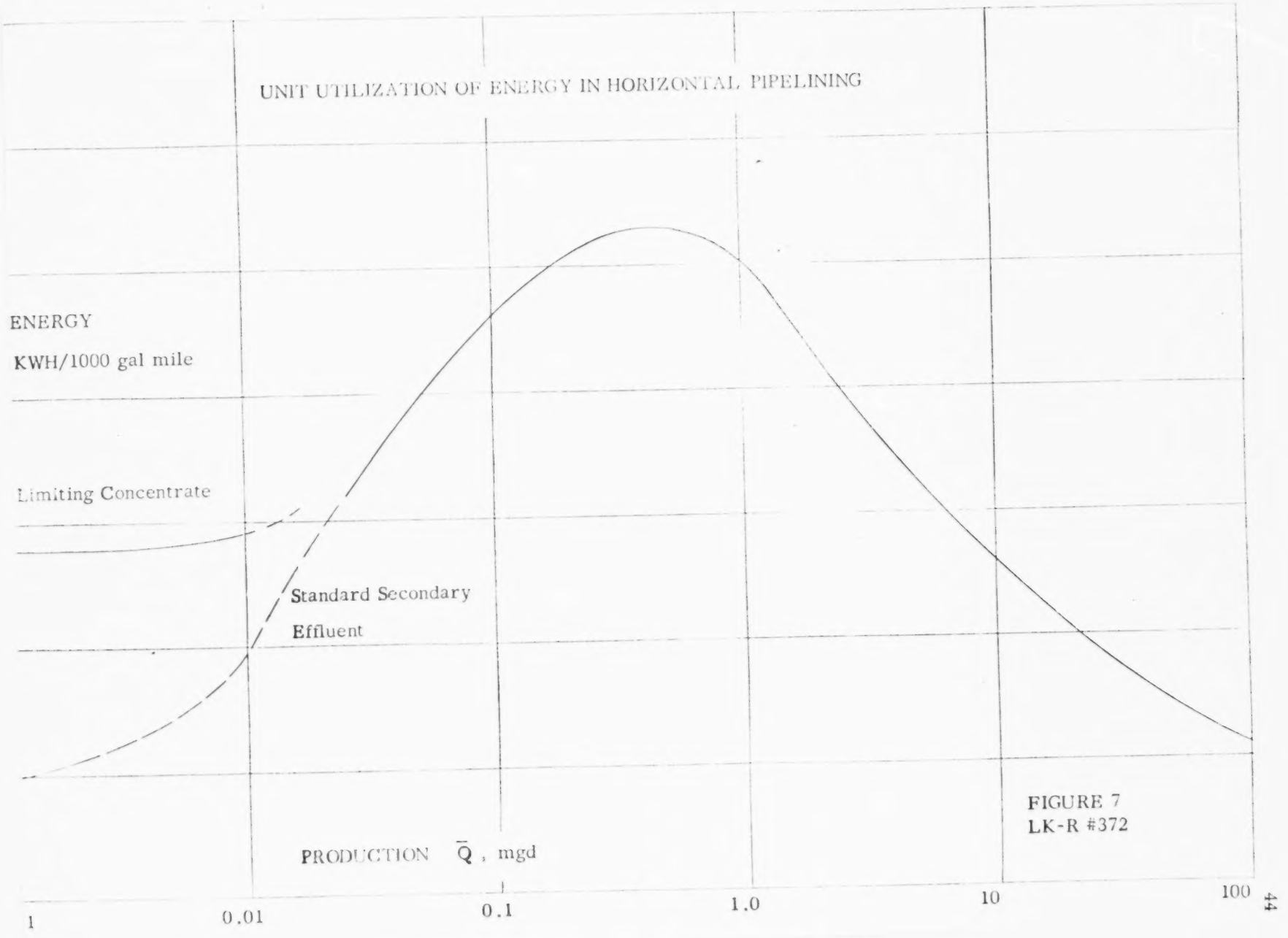


FIGURE 7
LK-R #372

KWH/1000 gal.-mi. As will be shown subsequently, the utilization of energy is so small that it does not matter what the capability of the pipeline is and so it does not matter how many trunk lines one assumes.

However, assuming the transport of 15 mgd for a 700-mile average haul, the maximum electric energy consumption would be 2.6×10^5 KWH/day or about 0.01% of total U. S. electrical generation.

The ton miles of pipelining for an average 700-mile haul would be 43.8×10^6 ton mi/day. In the pipelining of crude oil and products (not including gas) there was handled 660×10^6 ton mi/day in 1962 (15). Thus, the ton miles of hauling for AWT waste would be about 6.6% of the current oil and products pipelining ton-miles. This figure is also insensitive to the number of trunk lines assumed.

The pipeline mileage however is directly dependent upon the number of lines assumed. With the assumption of 100 lines, there would be required 70,000 miles of new line. The present installation (1962) of crude oil and products pipelines is 155,053 miles and of natural gas pipelines and utility mains 663,560 miles, for a total of 818,613 miles (17). Therefore, AWT pipeline mileage would amount to about 8.8% of the present installation.

About 410,000 of this total is distribution main (for gas). If one excludes distribution main from the computations, the AWT pipeline mileage would be about 17% of the present installed mileage. This figure is sensitive to the assumption as to the number of trunk-lines.

While such a figure (as 17%) presages a favorable economic climate for the pipelining industry, it by no means constitutes a logistical imbalance since, of course, the 8%, or 17%, would not be built in a single year but spread over a decade or more.

In summary, there do not seem to be any great impact or logistical imbalances in energy for pipelining or in ton miles conveyed. For total pipeline mileage there may be a slight impact, but this figure is highly dependent on the assumption, not now verifiable, of the number of trunk lines involved.

At 700 miles haul it is economic to preconcentrate to the equivalent of 99.9% recovery prior to pipelining at almost any flow rate, and at any % recovery below about 99.5. Thus at 98% recovery for example the utilizations computed for pipelining would be the same as for 99.9%.

Optimum Grouping — But very preliminary unverified projections as to optimum disposal groupings from the other current study under the Advanced Waste Treatment Research Program (16) suggest that the pattern of group disposal by conveyance to the ocean will comprise a band around the coastline of the order of 100 miles deep. But this conveyance will be by truck or rail and not by pipeline.

In the remainder of the country, optimum group disposal would be by some of the other methods, i.e., injection, incineration, etc. with communities grouped in economic optimum cells. However, the sizes of the cells and the daily volumes involved for the various segments of the hauls are such that this collection, estimated as of the order of 2×10^6 ton mi/day, would also be by truck or rail and not by pipeline.

Accordingly, if this turns out to be the real pattern of ultimate disposal, there will be no ultimate disposal by pipelining and, thus, no possibility of logistical imbalance in that sphere.

ULTIMATE DISPOSAL BY INJECTION

Injection wells for ultimate disposal also show a strong scale economy but this vanishes at 2 mgd which is about the highest capability that can be taken for an injection well. As with pipelining, it is uncertain what the optimum grouping might be but, for the present study, let it be assumed, as the worst case, that every sewered community on AWT in the model has, on the average, 1 injection well. This would mean a total installation of 11,000 wells.

The total number of producing oil and gas wells in operation at the end of 1962 was 596,385 (17). The 11,000 wells would amount to 1.8% of the existing wells.

In 1962, the oil and gas industry completed 44,000 wells (not including exploratory and test holes). The capability of the industry is higher than this, however. For example, in 1957 there were 57,000 wells completed. Accordingly the drilling industry could complete the 1962 compliment of 44,000 wells plus 11,000 wells for ultimate disposal in a single year, and still have several thousand wells capacity to spare.

The total footage drilled in 1962 was 198.5×10^6 ft. The average depth of wells drilled in that year was 4300 feet. This depth is probably about the minimum that would be necessary for injection wells for ultimate disposal. If it be assumed that the average ultimate disposal well reached 10,000 feet, there would be needed for the model 110×10^6 ft. of drilling. This is about 55% of one year's footage in the oil and gas industry. Again, this would be a favorable climate for the drilling industry but it would by no means upset the economy. In the first place, probably not more than one-half of the nation is suitable for injection wells, and secondly, the construction of such injection wells for AWT would be spread over a decade or more.

CHAPTER 6

PROCESSING PROCEDURES

Introduction

Determination of Average Per Capita Flow

Processing the IMWF Data

- Introduction
- Determination of g
- Determination of f
- Determination of Q_o
- Computation of Q and Qf
- Treatment of Irrigation Discharges

Plotting and Cumulation of the Data

Selection of Cities for Cumulation

INTRODUCTION

This Chapter details the processing procedures and computations that were used in producing the data on which Chapters 3 and 4 are based.

The basic document is the Inventory of Municipal Waste Facilities (IMWF), 1962, and the Municipal Water Facilities Inventory, Communities of 25,000 Population and Over, 1962 (18, 19). The statistical summary of the 1962 IMWF has not yet been issued but that for the 1957 Inventory (1) showed a total of 11,131 sewered communities. The 1962 Inventory probably contains more than this number. On the other hand, not every entry in the Inventory resulted in an entry in the present study since some of the entries for multiple facilities with discharges located close together were combined for the present study.

Since some of the entries lacked data for the volume of sewage flows, these missing entries were synthesized by application of an average per-capita-sewage-flow figure for each state. These average per capita sewage flows, $\overline{PC}$'s, were developed from those entries in each state for which both population or population served and volume of sewage flow were given.

The processing of the data consisted of the determination, operating by a set of rules on the information given for each entry of Q_o, the volume of sewage flow, Q, the volume of sewage reaching the stream, g, the fraction of the sewage flow which reaches the stream, f, the fraction of BOD removed before discharge, and Qf, the fraction of BOD removed weighted by the flow reaching the stream.

In the West, where discharge to irrigation uses is common, these computations were made separately for the irrigation discharges, for the non-irrigation discharges, and for their sums.

The data for each community were plotted on 1:1,000,000 scale drainage basin maps and cumulated downstream for the main streams and major tributaries, accumulation points being at their confluences. The accumulation points represented at least 95 miles of stream and there was an accumulation point for every stream or reach of 95-mile length. The cumulations gave total waste flow reaching the stream and fraction BOD removed weighted by total waste flow reaching the stream, both for the non-irrigation flow and for the total flow.

For determining the fraction of upstream wastes in surface water sources, there were selected 155 cities having single surface water sources and a population greater than 25,000.

DETERMINATION OF AVERAGE PER CAPITA WASTE FLOW

Not all of the entries in the IMWF provide data on the volume of sewage flow. However, some of the entries lacking flow figures did provide population or population-served data. In order to generate flows from population or population served data, it was necessary to develop average per capita waste flows. This was done for each state and for three population classes in each:

Less than 10,000 population or population served, $\overline{PC}_1$
10,000-100,000 population or population served $\overline{PC}_2$
Greater than 100,000 population $\overline{PC}_3$

For each state and population category there were summed the total population or, preferably, population-served and the total flow for all entries providing both data with the following exceptions. For a number of entries it was found that the listed flow corresponded precisely to 100 gallons per capita per day (gpcd). It was considered that these had been estimated by application of a highly conventionalized gpcd factor and these were excluded from the $\overline{PC}$ computation. Other estimated flows not resulting from a precise 100 gpcd factor were included in the computation with the thought that the estimate was an actual estimate and represented the approximate flow. The results are shown in Table 13.

The resulting average per capita flows, $\overline{PC}$'s, are as follows:

$$\overline{PC}_1 = 131 \text{ gal/capita-day}$$
$$\overline{PC}_2 = 120 \text{ " " "}$$
$$\overline{PC}_3 = 155 \text{ " " "}$$
$$\overline{PC}_{all} = 141 \text{ gal/capita-day}$$

TABLE 13

PER CAPITA WASTE FLOW, BY STATES AND POPULATION CATEGORIES

State	$\overline{PC}_1$ gpcd	No. of Entries Used	$\overline{PC}_2$ gpcd	No. of Entries Used	$\overline{PC}_3$ gpcd	No. of Entries Used	$\overline{PC}_{all}$ gpcd
Alabama	137	32	124	9	-	-	127
Arizona	77	66	128	10	86	1	101
Arkansas	94	24	59	11	-	-	68
California	330	270	55	93	103	16	104
Colorado	355	13	96	1	160	1	147
Connecticut	138	53	137	28	187	3	151
Delaware	140	7	-	-	253	1	242
Florida	119	134	143	21	135	2	134
Georgia	119	128	125	15	84	4	100
Idaho	295	32	164	7	-	-	199
Illinois	99	363	117	53	259	5	211
Indiana	134	52	174	37	177	6	171
Iowa	115	147	172	11	79	1	136
Kansas	96	182	93	21	67	1	91
Kentucky	157	5	132	2	-	-	136
Louisiana	115	51	146	8	-	-	135
Maine	173	5	181	1	-	-	177
Maryland	245	1	-	-	-	-	245
Massachusetts	178	71	125	23	154	3	147
Michigan	112	141	136	36	88	5	114
Minnesota	96	21	105	3	139	1	135
Mississippi	149	2	194	2	-	-	164
Missouri	73	77	199	7	-	-	149
Montana	198	74	168	5	-	-	181
Nebraska	150	26	-	-	-	-	150
Nevada	138	18	151	4	-	-	149
New Hampshire	178	9	230	1	-	-	197
New Jersey	152	11	152	8	386	2	346
New Mexico	85	51	101	4	110	1	101
New York	132	211	141	48	143	14	142
North Carolina	131	179	120	22	136	1	125
North Dakota	112	29	58	4	-	-	71
Ohio	112	204	119	65	156	11	135
Oklahoma	92	210	98	18	107	2	99
Oregon	199	21	162	7	-	-	173
Pennsylvania	100	287	103	46	125	5	112
Rhode Island	134	17	134	6	173	2	156
South Carolina	96	110	151	12	-	-	150
South Dakota	84	174	123	9	-	-	105
Tennessee	146	40	158	11	228	2	185
Texas	95	374	95	60	107	8	100
Utah	165	18	174	8	174	1	173
Vermont	204	18	158	3	-	-	184
Virginia	203	55	192	1	75	1	124
Washington	179	57	190	16	-	-	187
West Virginia	89	1	64	1	-	-	47
Wisconsin	126	350	178	29	188	2	171
Wyoming	178	3	109	2	-	-	110

This indicates that the national average flow is 141 gpcd. However, the per capita flow to be used to generate the highest percentage of correct community flows would be 131 gpcd since communities in the less than 10,000 population category are, by far, the most numerous in the IMWF.

Figure 8 shows, for this most numerous category, the $\overline{PC}_1$ for the various states in an attempt to determine if any regionalization of $\overline{PC}$'s is possible. The region of highest $\overline{PC}$'s is in the northwest on the arc from Colorado to California where the range is 178 to 330 gpcd and the average 250. The region of lowest $\overline{PC}_1$'s in the nation is the contiguous southwestern arc from Arizona to Illinois with no state $\overline{PC}_1$ above 100. Nevada and Utah are intermediate between the above two regions. Another high $\overline{PC}_1$ region is the northeastern arc from Virginia to Maine where the average is 180 gpcd. The remainder of the country from Florida to Michigan and Michigan to the Dakotas is in the middle range and somewhat heterogeneous. The map presents the distribution of $\overline{PC}_1$'s. Note that the average $\overline{PC}$ for all available cities in each state may be quite different from the $\overline{PC}_1$, as may be seen from Table 13.

Inspection of Table 13 suggests that the trend of $\overline{PC}$'s with population is quite erratic. However, application of the statistical sign test to the 48 state data shows that there is an upward trend from $\overline{PC}_1$ to $\overline{PC}_2$ at a .25 level of significance. This means that the probability is only 0.25 that the upward trend conclusion is incorrect. The test applied to $\overline{PC}_2$ and $\overline{PC}_3$ indicates an upward trend at the 0.05 level of significance meaning that the probability that there is no such trend is only 0.05. The $\overline{PC}$'s so developed were applied to the appropriate entries lacking flow data in the processing step to generate synthetic waste volumes as described in the next section.

PROCESSING THE IMWF DATA

Introduction

The following symbols and concepts were used in the processing:

- Q_o = discharged from plant, mgd
- g = fraction of Q_o which reaches the stream
- Q = flow resulting from Q_o which reaches the stream, mgd
- f_e = estimated fraction of BOD removed from Q before discharged to stream
- f_p = known fraction of BOD removed from Q before discharge to stream
- f = final choice for fraction of BOD removed from Q before discharge to stream
- Q_f = fraction of BOD removed weighted by flow reaching stream

The aim of the processing is to develop a set of two numbers associated with each sewered community, one representing the volume contribution of waste liquid

AVERAGE WASTE FLOW, gpcd, BY STATE AND REGION

COMMUNITIES OF <10,000

FIGURE 8
LK-R #379

reaching the stream and the other representing the fraction of BOD removed in treatment weighted by the flow reaching the stream. In the cumulation and summation for the final use to which these data are put, $\Sigma(Qf)/\Sigma Q$ becomes the weighted fraction of BOD removed, and hence, the f index number measuring the weighted degree of treatment of upstream discharges.

Determination of g

The first step in the processing is the determination of g, the fraction of the discharge which reaches the stream. Before proceding to that determination it was possible to eliminate those entries for which there was no population, population-served, volume discharged, or design volume. For these entries there was no possibility of computing a discharge rate. It was also possible to eliminate from further processing those entries in which the population-served occurred in parentheses, indicating that these entries were included in some other facility already existing as an entry.

For the remaining entries, the determination of g fell into six cases as follows.

In Case I, g was taken as zero and, since this meant that none of the discharge reached a stream of interest to the study, the entry could be excluded from further processing and plotting. This case comprises those entries in which the "discharge to" column contains:

Industrial reclamation
Ocean
Slough (on coast or tidewater)
Bayou (on coast or tidewater)
Tidewater
Bay
Gulf
Drainage well (greater than 1,000 feet deep and near the seacoast)

In Case II, g was taken at 1.0, in other words all of the Q_o reached the stream. This case comprised entries in which the "discharge to" column there occurred:

Wet weather lake
Lake (no effluent)
Lagoon
River, creek, or tributary
Lake
Drainage ditch
Slough (if inland)
Bayou (if inland)

Dry run to some river
Ditch to some river
Any other category "to some river"
Lava sink hole
Subsurface
Canal
Swamp
Channel
County Ditch
Seepage lagoon
Drainage well (less than 1,000 feet deep)
No discharge (when treatment column indicated lagoon)

The concept for Case II is that, in these cases, all of the discharge reaches the stream without any evaporation or transpiration losses.

In case III, g is taken as 0.20, for it is assumed that the discharge is similar to irrigation in which there is an intermittent spreading on the land such that a considerable amount of evaporation and transpiration occurs before the effluent reaches the ground water body. But, once it reaches the ground water body, it ultimately finds its way into the stream. It is recognized that the point of entry into the stream may be far removed from the discharge point but lacking any means to determine this, it is taken as occurring near the discharge point. The reasoning also applies to the non-identity of the surface-water divide with the ground water divide. Case III occurred when the "discharge to" column contained:

Dry gulch
Dry water course
Dry creek
Dry draw
Dry channel
Dry tributary
Dry ditch
Ditch
Dry bed
Ravine
Draw
Roadside ditch
Gully
Storm ditch
Wash
Arroyo
Watershed, when irrigation appeared in treatment column

****

Note: The above entries were taken as Case III if they appeared unqualified. If they appeared with a qualification indicating they were a direct channel to some river, for example "dry creek to (named) river", then they were placed in Case II.

Irrigation, no effluent (if due to irrigation)
Land
Percolation, no discharge

In Case IV were placed those entries containing no information in the "discharge to" column and no other apparent way of determining this datum. The g for this case was arbitrarily taken at 1.0 unless irrigation was indicated in the treatment column; in this case, g was taken at 0.20.

In Case V were placed those entries in which the treatment column contained an evaporation lagoon; in this c ase, the g was arbitrarily taken as one-half of the g determined from Case II or III. This is based on the assumption that, in an evaporation lagoon, on the average about 50% is evaporated and the remainder is lost by seepage or overflow.

In Case VI were placed those entries indicating a seasonal population load; in this case, g was taken as one-third the values determined by the preceding formulae.

Determination of f

This fraction is the fraction of BOD removed from Q before it reaches the stream. It is not precisely the residual BOD reaching the stream divided by the original BOD. The reason is that, if evaporation occurs on the way to the stream, this evaporation will remove water but not BOD. In certain cases, f, the final choi ce, may be directly determined from the "discharge to" column if "percolation" is indicated. Here, an f of 0.90 (20) is assigned. Entries indicating "percolation" were placed in Case I and were those whose "discharge to" column was designated:

Storm ditch
Irrigation
Dry creek
Dry channel
Dry ditch
Roadside ditch
Wash
Dry water course
Dry draw
Dry tributary
Ditch
Gully
Arroyo
Watershed if irrigation occurs in treatment column
********Note: The above applies if the entry is not qualified by "to some river". If that is the case, f cannot be taken as 0.90 but must be determined as in the following section.

Wet weather lake
Lagoon
Lake (no effluent)
No effluent
Land
Percolation
Draw
Seepage lagoon
Drainage well
No overflow
Lava sinkhole
Subsurface
No discharge

In Case II are placed all other entries not in Case I. For these entries the procedure is to determine f_e and f_p, the estimated and precise fractions removed, and on the basis of these decide which will be chosen as the final f.

The estimated fraction removed, f_e, is determined by the listing in the treatment column as follows:

Aeration, trickling filter, oxidation lagoon, or irrigation: $f_e = 0.90$
Intermittent filter: $f_e = 0.70$
Settling tank or settling lagoon: $f_e = 0.35$
None of the above: $f_e = 0$

f_e is assigned corresponding to the treatment type which produces the highest f_e from the above table. The figures 0.9, 0.35 and 0 are assigned as conventional fractions removed for secondary treatment, primary treatment and no treatment as concurred in through discussions with U. S. P. H. S. personnel (21).

The figures of 0.70 and 0.50 for intermittent sand filters and rapid sand filters were assigned as the result of a sample study of entries for which an f_p was known and which had rapid or intermittent sand filters other than those included in a system also involving secondary treatment or lagoons. The average for six rapid sand filter entries was 0.51 and for 21 intermittent sand filter entries was 0.77.

The IMWF gives, in many cases, the population equivalent of the discharged wastes and the population equivalent of the untreated wastes. If these data are given, the precise fraction removed is computed by:

$$f_p = 1 - (\text{PE treated waste}/\text{PE untreated waste})$$

If no data are given in the population equivalent column, then f_p cannot be computed.

For entries falling in Case I determined by the "discharge to" column, the final selection, f, is 0.90 regardless of f or f_p. If there are no data in the population equivalent column, f_p cannot be computed and, if the entry is not a Case I entry with $f = 0.9$, the f is taken as f_e.

If both f_e and f_p are available then the choice of the final f is made according to the following:

If $f_e = 0.9$ and $f_p = 0.46$ to 1, choose $f = f_p$, but
if $f_e = 0.9$ and $f_p = 0$ to 0.45, choose $f = 0.9$

If $f_e = 0.35$ and $f_p = 0$ to 0.49, choose $f = f_p$, but
if $f_e = 0.35$ and $f_p = 0.50$ to 1, choose $f = 0.35$

If $f_e = 0$ and $f_p = 0$ to 0.24, choose $f = f_p$, but
if $f_e = 0$ and $f_p = 0.25$ to 1, choose $f = 0$.

The basis of this is that there usually will be a discrepancy between the estimated or conventional fraction removed, f_e, and the computed or precise fraction removed, f_p. When f_p differs slightly from f_e it is assumed that this is due to normal variation in operating efficiency. When the f_p differs widely from f_e, then the final chosen f is taken as f_e considering that there must be some error in the data. An analysis of some of these data is given in another section.

A similar rule was not established for f_e's or 0.50 or 0.70 resulting from intermittent sand filters or rapid sand filters. Accordingly, if f_e was assigned 0.50 or 0.70 by virtue of this type of treatment, the final f was taken as f_p if available and f_e if not.

Determination of Q_o

Q_o is the sewage flow of a community. If the flow is given in the IMWF and is not the product of population-served times 100 gpcd, then the figure given in the IMWF was taken for Q_o.

If the flow was not given or was the result of multiplying a population-served by 100 gpcd, then Q_o was obtained by the application of the appropriate $\overline{PC}$ (for the population class and state) to the population-served if given, or if not given, to the 1960 population. If Q_o could not be determined in this manner for lack of information, then it was assumed that the average flow was 50% of the design flow and Q_o was taken as 0.5 times the design flow as given in the IMWF. If the design flow in turn was not given, then the entry was eliminated from further processing and plotting.

Computation of Q and Qf

Having determined g, f, and Q_o, there remains the computation for each community of:

$$Q = gQ_o,$$

and

$$Qf = gfQ_o$$

Q is the volume of effluent from a community which actually reaches the stream and Qf is the figure indicating the degree of treatment weighted by the volume of effluent that reaches the stream.

Treatment of Irrigation Discharges

Irrigation as a final disposition of a sewage discharge was given an f_e of 0.9 reflecting the high degree of treatment achieved by intermittent spreading. Irrigation discharge is uncommon in the East but in the West is quite common. The possibility thus arose that a stream would show an f index of 0.9 largely because most of the discharges in its basin were for irrigation. By the system used, such a stream would be considered in the market for advanced waste treatment. However, this would not actually be the case.

When secondary treatment yields an f of 0.9, the discharge is concentrated in one process stream, i.e., the secondary treatment plant effluent being discharged. Such a stream could be conveyed to an advanced waste treatment plant and utilized as feed. However, when the 0.9 is achieved as a result of irrigation, this 0.9 liquid is not recoverable for use as advanced waste treatment feed. Accordingly, it would be an error to place in the advanced waste treatment market the river basins in which the 0.9 discharge was obtained largely through irrigation use.

It is not possible to completely eliminate the ambiguity in the results brought about by this concept, because the same cumulation of Q, the volume discharge reaching the stream, was to be used, both for determining the cumulative f index, and also for determining the percentage of upstream wastes in surface supplies. However, in an attempt to quantify the ambiguity and to allow a rejection of a 0.9 stream if warranted by a high fraction of irrigation discharges, a separate cumulation was made of the Q and Qf of irrigation discharges, land applications, etc. The cumulations actually made, therefore, were Q and Qf for non-irrigation discharges, and Q and Qf for irrigation-type discharges.

Tabulations of the type shown in Table 1, Chapter 3 were made of accumulation points having f 'index factors from non-irrigation discharges greater than 0.8. Then, for these points, the corresponding f index for all discharges was tabulated and there were added to the Table a number of accumulation points for which the f index for non-irrigation discharges was less than 0.8 but the f index for all discharges was greater than 0.8. The number of entries so added to the Table was 16, excluding those which were made up almost exclusively of irrigation discharges and thus excluded from the AWT market. All of

these 16 were in Texas. One of them fell in the f = .85-.90 class and the remaining 15 fell in the f = .80-.85 class. Analysis then showed that of all of the entries in the Table, only a very few had an appreciable portion of irrigation-type discharges and these are the ones indicated in Notes 2 and 3 of the Table.

A further study then showed that a very high percentage of the discharges used for irrigation were already in the 0.90 class prior to the irrigation use. Thus, a process stream of f = 0.9 was, indeed, actually available and could have been used as an AWT feed. Further consideration, however, develops the concept that, if such discharges were diverted to AWT and away from irrigation, it would be necessary, in order not to upset the irrigation economy, to supply an equal amount of water from some other source for irrigation. Thus, the concept that such basins are excluded from the AWT market applies whether or not the processed stream is at 0.9 before the irrigation application.

PLOTTING AND CUMULATION OF DATA

The basic maps on which the data were plotted and cumulated were the River Basin maps provided by the Interagency Committee on Water Resources (22). These maps, in 80 sheets, cover the drainage basins of the nation showing all surface streams (and hydrologic stations) on the scale of 1:1,000,000. Also used in plotting, where the communities were very dense, were the corresponding maps from an earlier (1959) edition of that reference of the scale of 1:625,000. Plotted on these maps were the communities corresponding to the IMWF entries, approximately 11,000 of them, the Q value, the f value, the $\boxed{Q}$ and $\boxed{f}$ values for that portion of the discharge which was of the irrigation type, and a dot locating the stream which the discharge reached.

The maps were then divided into drainage basins for cumulation. Drainage basins for cumulation were drawn so as to comprise at least 6 inches (about 95 miles) of stream including first or higher order tributaries. If a tributary and one or more of its successive tributaries was 6 inches long, a drainage area was drawn around its drainage basin and an accumulation point placed at its confluence with the main stream. If a tributary was less than 6 inches in length, it was not cumulated separately but was included in the main stream at the point of confluence without an accumulation point. If this procedure left a length of stream greater than 12 inches without a cumulation point, then an arbitrary accumulation point was set 6 inches upstream from the last accumulation point reading upstream. The result was that all streams separately cumulated were between 6 inches and 12 inches in length. Streams less than 6 inches in length were not separately cumulated, and, if they were coastal streams, i.e., not tributary to a main stream, then they were not cumulated at all.

At a confluence, accumulation points were placed on the tributary and on the main stream above and below the confluence. Accumulation points were also placed at the points where a stream left a map.

For international boundary streams and for streams which entered the United States from Canada or had portions of their course in Canada, it was not possible to obtain the data for the municipal discharges in Mexico or Canada. Accordingly, the cumulations involve only the United States contributions to such rivers.

SELECTION FOR CITIES FOR CUMULATION

For the study on fraction of stream flow comprised of upstream municipal wastes, it was necessary to select a number of cities for study. Cities were selected which had a surface supply and which, with a few exceptions, drew on only one source, i.e., one river or one reservoir, and for which that river had a nearby gaging station. Such cities were selected from the Municipal Water Facilities Inventory (19). There are 414 cities of over 25,000 population supplied by surface water and, of these, only 155 could be selected as fitting the above criteria. One reason for this was that many of the 414 entries constitute suburban districts to major cities such that it would not have been profitable to separate out the close-lying intakes.

A nearby gaging station was selected and the flow at the gaging station was considered to be the flow at the municipal intake with the exception that an adjustment was made for confluences and discharges occurring between the gaging station and the approximate location of the municipal intake.

The river-flow data used was that from the water year 1961 (October 1960-September 1961) as appearing in Reference 23. The two flows chosen were the average stream flow for 1961 and the average flow for the minimum flow month for 1961. The year was approximately contemporary with the data in the Inventory Municipal Waste Facilities. The minimum flow was chosen somewhat arbitrarily and largely because the only other available minimum, that for the minimum day, seemed too extreme for general use.

In a few cases some radical error may have been introduced due to lack of precise knowledge concerning location of a municipal intake. For example, if a selected gaging station is below a reservoir but the actual municipal intake is from the reservoir, then the average and minimum flows at the gaging station may not represent the average and minimum flows entering the reservoir. For the most part, the probability is high that the average flow below the reservoir when adjusted for the withdrawal from the reservoir will approximate the average flow into the reservoir, i.e., the change in reservoir contents over a one-year period will be small compared to the total annual flow. However, this is not the case for minimum monthly flows. It is possible that the minimum monthly flow below a reservoir be zero while the minimum monthly flow above the reservoir be some positive value. In such cases, the tabulated figure for the percentage of upstream waste in the minimum monthly flow at the intake would be in major error.

Even in the case in which the gaging station is upstream of the reservoir but the intake is from the reservoir, there will be a major error in the low-flow percentage due to the fact that the composition of the reservoir with respect to upstream municipal wastes will represent some average because of mixing, unless it happens that during the low-flow month the reservoir contents were at a very low stage. A considerable amount of detailed work on individual cases would have been required to eliminate errors of this type, starting with the primary difficulty that, in many cases, the IMWF cites as a source only the river involved without describing whether the withdrawal is by way of a reservoir. Since the purpose of the study was to obtain some general nationwide indications, such an amount of work to obtain accuracy in such exceptional cases was not warranted.

In a few cases, the data presented may not be truly representative of the conditions at the municipal intake due to some deviation from a typical surface water supply situation, usually involving multiple sources which were here taken as a single source. For example, for the city of Shreveport, Entry No. 33, the municipal source is Cross Lake of which a principal tributary is Paw Paw Bayou. Paw Paw Bayou has the only gaging station in the vicinity and, therefore, was chosen as the gaging station for Shreveport. The only municipal discharge reaching Cross Lake is from Waskom, Texas, a small community having land discharge. (Indeed it is not certain whether this Waskom discharge reaches Paw Paw Bayou or reaches Cross Bayou, another tributary to Cross Lake. The data in the Table are computed as if the Waskom discharge occurred to Paw Paw Bayou.) The percentage given, then, is not the percentage for the Shreveport intake at the head of Cross Lake, but the percentage at that point must be less than the percentage given in the Table, since Waskom's discharge certainly reaches Cross Lake and the flow into Cross Lake is greater than the flow from Paw Paw Bayou. There may be other errors of this general type relating to multiple sources in the Table, but it would not be possible to eliminate all of them short of a field study for the conditions for each city.

In addition to the cumulations made to confluences, cumulations of Q were also made to the selected gaging stations from which the percentage of upstream municipal waste in the flow was computed.

CHAPTER 7

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